PRACTICAL X RAY WORK

FRANK T. ADDYMAN
B.Sc. (LOND.)

Frank H. Hoolt, M.D.
1914.

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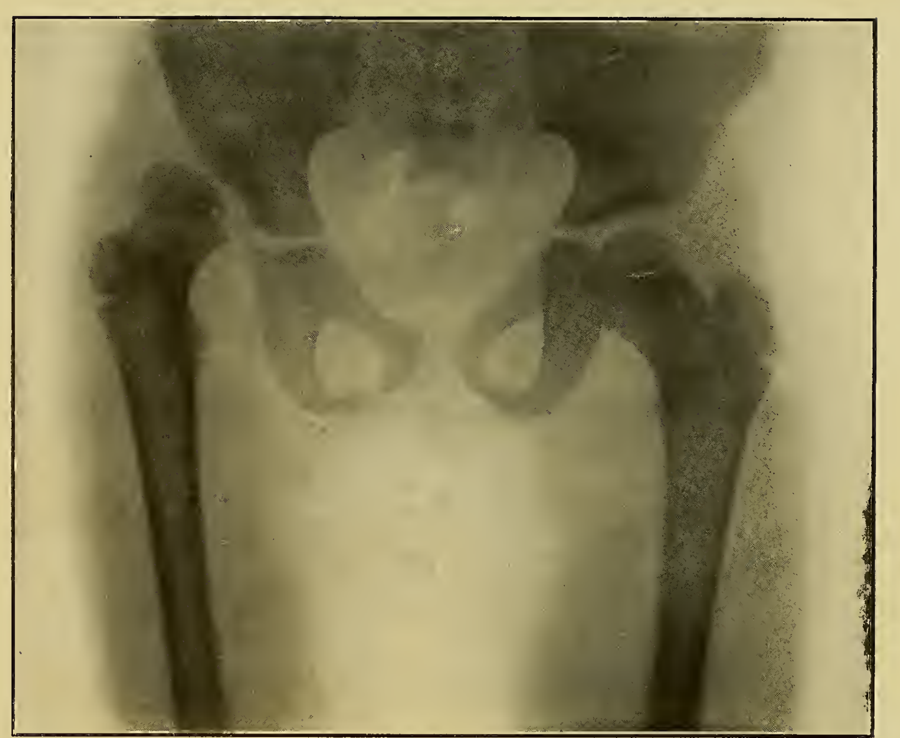
TO THE MEMORY OF MY FATHER,

THE LATE

REV. THOMAS ADDYMAN,

THIS WORK IS DEDICATED.



Frontispiece.—Congenital Dislocation of Hip-joint.

PRACTICAL X RAY WORK

BY

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WITH FIFTY-TWO ILLUSTRATIONS AND TWELVE FULL-PAGE PLATES

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PREFACE.

In trying to give a description of X ray work of use to medical men I encounter two principal difficulties. The first is that some, but not all, are well acquainted with the element of electrical science, and the second is that the use of a Crookes' tube cannot be learned by reading a book.

As the majority of English medical practitioners hold the joint qualification of the Royal Colleges of Physicians and Surgeons, I have taken as my starting-point the syllabus of the first examination of the Conjoint Board. Those gentlemen who are skilled electricians, and who may read this book, will therefore pardon my including explanations of electrical terms. At the same time, the explanations given will be of little use to any who have not mastered the elements of the science to the extent required for the examination just mentioned.

As to the second difficulty, I have done my best to set forth, in the chapter on "Tubes," some account of the vagaries of these pieces of apparatus. If the reader should wish to learn more about them he must do so practically. He should take his apparatus into a dark-room and examine his hand with a fluorescent screen. He should watch the changes which take place in the shadows when the spark is increased. He should watch the distortion of the shadows as his hand moves from side to side. He should watch all the subtle changes in hardness and definition. Then, presuming that he is using a hard tube, before finishing he should reverse the current for a few moments, and on bringing it back to its correct direction he will be able to see the startling but evanescent change in the blackness of the shadows. The effect of heat on the tube should be noticed. In fact, every varying mood should be ascertained as nearly as possible.

An hour or two spent in this way will be of great value to the beginner. Radiography, or the use of photographic plates, is not so easily learned. Experience is just as necessary here as in ordinary photography.

Presuming, however, that the reader has the amount of electrical knowledge which will overcome the first difficulty, and has the energy to overcome the second difficulty, it is hoped that this book may help him to become expert in the use of X rays.

The book is divided into three parts, of which the first is historical.

The second describes the apparatus most generally used, giving especial attention to induction coils and focus tubes.

The third part does not attempt to do away with the necessity for practice, but describes the general practical conditions under which X ray work is used, and gives hints as to how some of the greater difficulties may be overcome.

F. T. A.

St. George's Hospital,
May, 1901.

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PART I.

HISTORICAL.

CHAPTER I.

INTRODUCTION.

X RAYS have been discovered so recently, and have been exploited to so great an extent in the columns of our newspapers, that it would seem hardly necessary to describe their peculiar powers. Nevertheless, a few remarks on the general scope of the work which may readily be performed by their aid, and its limitations, will not be out of place here, as they will help to give clear ideas as to what results the worker may expect.

The word transparent is used generally to describe those substances through which *light* can pass; and by the word light is meant those vibrations of the luminiferous ether which affect the human eye. Glass and water are transparent in this sense. If we extend the meaning of the word to other forms of radiant energy, we at once get outside our everyday experiences. Thus, a strong solution of iodine, although nearly black in colour, and quite opaque to light rays, is easily penetrated by heat rays. On the other hand, a sheet of glass, though transparent to light, makes a very effective fire-screen, as it is somewhat opaque to heat rays.

These heat rays are closely related to rays of light, being transverse vibrations of the ether, in which the waves have a longer periodic time than those of light. Again, there are other rays of more rapid vibration than light, known as ultra-violet rays, which, though they do not produce the sensation of light, have a very definite effect on a photographic plate.

The popular idea of transparency then is limited by the sensations of the eye as an optical instrument. But since we already know that different substances are transparent to different kinds of rays, it is readily conceivable that the discovery of "a new form of radiation"[1] would give rays capable of penetrating many substances hitherto considered quite opaque. Indeed, we may consider that there is no substance absolutely opaque to this new form of radiation known as the X rays. Thus a rifle barrel, which one would expect to be very opaque, has been penetrated, in a beautiful radiogram taken by Prof. Roentgen, which shows clearly the leaden bullets of the cartridges lying within.[2]

Having thus secured a form of radiation to which all things are transparent in varying degrees, the next difficulty is to render the rays perceptible by the eye.

This may be accomplished in two ways:—

Firstly.—By means of a photographic plate. If the X rays fall on a dry plate, they will have exactly the same effect as light rays, that is, they will produce no immediate result, but, on development, the plate will turn black.

As an example of the use of a photographic plate, we may take the photograph of a hand shown in Plate I. Here the rays have been passed through the hand and then allowed to act on the photographic plate. No part of the hand allows

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[1] The title of Roentgen's original paper.

[2] "With a tube that has become, in this way, very hard, I have obtained a very fine radiograph of the double barrel of a gun loaded with cartridges; the flaws in the steel of the barrel, etc., are very clearly and sharply shown."—"Further Observations on the Properties of X Rays," W. C. Roentgen, *Annalen der Physik und Chemie.*

Plate I.—Needle in Finger.

the rays to pass so freely as they do through the air, so a shadow is thrown on the plate showing the general outline of the hand. The flesh is, however, much more transparent than the bones, so the bones cast a deeper shadow. More opaque still are the metallic objects, such as the portion of a needle embedded in the finger, the rings and the bracelet, which cast still deeper shadows than the bones.

Secondly.—By means of a fluorescent screen. This is a much more rapid method, as the operator can actually *see* the shadow without photographing it.

It is well known that there are certain substances, such as fluorescein and eosin, which have the power of absorbing invisible ultra-violet rays, and giving out, in exchange, visible light rays ; thus with a proper arrangement of apparatus these chemicals may appear luminous in the dark.

In the same way there are certain chemicals, which will be described in detail in a later chapter of this book, which are able to transform invisible X rays into rays of light.

If a substance possessing this peculiar power be spread out on a sheet of cardboard which is very transparent to the new form of radiation, and the X rays are allowed to fall upon it in a dark room, the sheet will glow with a phosphorescent light wherever the rays strike the chemical.

Supposing that the hand photographed in Plate I. had been held between the source of X rays and the "*screen*," as the prepared piece of cardboard is called, then the flesh would cast a slight shadow, the bones would cast a deeper shadow, and the metallic substances being nearly opaque would allow practically no rays to pass through and would leave a black spot on the screen. In this way a shadow would be actually seen, similar to the one in the photograph.

The methods of producing and utilising the X rays are described in this book. Naturally their value was first appreciated in the realm of surgery. The fact that the bones are more opaque than the flesh at once suggests its use in examining bones, and the opacity of lead and many other metals suggests its use in finding bullets and foreign bodies such as needles. Up to the present these are the two chief uses of the X rays, but there are other great possibilities.

I mentioned just now that Prof. Roentgen had penetrated a steel rifle barrel, showing the bullet within. The same photograph would show up any flaw in the steel of the barrel. This suggests the employment of these rays in examining castings for defects.

The difference in the transparency of precious stones and their imitations has already led to their use in detecting false jewels. In mineralogy and mineralogical chemistry, and in testing the homogeneity of alloys, further applications have been found, whilst physicians have also begun to find uses for the X rays in the treatment of skin diseases.

With regard to limitations, it must be remembered that all the photographs or screen pictures produced by the X rays are only photographs or pictures of shadows. No substance has yet been found which will reflect or refract them,[1] so that the use of lenses is seemingly impossible. At present the most beautiful application is in the production of stereoscopic shadows. Still, these remain mere shadows, and a shadow is not always the easiest thing in the world to interpret.

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[1] "Finely powdered substances, in sufficient thicknesses, allow only a very little of the incident light to pass through, and that is dispersed by refraction and reflection. Now, powdered substances are quite as transparent to X rays as are solid bodies of equal mass. Hence, it is proved that refraction and regular reflection do not exist to a noticeable degree. The experiments were carried out with finely powdered rock salt, with powdered electrolytic silver, and with the zinc powder much used in chemical work. In no case was any difference observed between the transparency of the powdered and solid substance, either when using the fluorescent screen or the photographic plate."—Roentgen.

CHAPTER II.

WORK LEADING UP TO THE DISCOVERY OF THE X RAYS.

In Prof. Silvanus P. Thompson's presidential address, delivered before the London Roentgen Society in November, 1897, there occurs the following paragraph:—

"In the history of science, nothing is more true than that the discoverer—even the greatest of discoverers—is but the descendant of his scientific forefathers, is always and essentially the product of the age into which he is born. Roentgen himself has frankly avowed the ancestry of his discoveries. He himself has stated that, being aware of the existence of unsolved problems respecting the emission of cathode rays in and by an electrically stimulated vacuum tube, he had for a long time followed, with the greatest interest, the researches of Hertz and Lenard, and had determined, so soon as he should find the necessary leisure, to make some researches of his own. Behind Roentgen, then, stand Lenard and Hertz; behind Hertz stand Crookes, and Varley, and Hittorf, and Sprengel, and Geissler; and so back to Hauksbee, and Boyle, and Otto Guericke, into the beginnings of modern science as it emerged from the vain imaginings of mediæval night."[1]

Thus to trace out all the events which made the discovery of X rays possible would mean writing the history of electrical science. Seeing, however, that X rays are produced in one way only, so far as we know, that is, by means of the Crookes'

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[1] *Archives of the Roentgen Ray*, ii., 24.

tube, the history here given will be merely that of the development of this piece of apparatus.

Ever since Otto von Guericke first devised an electrical machine which would give a spark, investigators have been attracted by those electrical phenomena in which light is produced. Towards the latter end of the eighteenth century the invention of plate machines made possible the study of many luminous effects, such as the zig-zag spark obtained by a discharge between two conductors, and the brush discharge from a single conductor. It was not, however, until the invention of the induction coil by Ruhmkorff that a high-pressure discharge was rendered thoroughly manageable. Since that time the discharge has been investigated under all conditions.

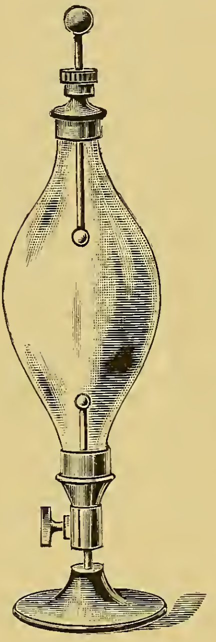

Fig. 1.—Electric egg.

It is to Sir William Crookes' investigations of the discharge through very high vacua that we owe the instrument whose full usefulness it was left to Prof. Roentgen to discover. But before detailing the work of Sir William Crookes, a few words should be said as to the knowledge which had already been gained of discharge effects through air at different pressures.

Most of these effects may be shown in a piece of apparatus known as the electric egg. It consists of a strong egg-shaped glass vessel with a stop-cock fixed at its lower end, and a brass rod cemented tightly into a hole at the upper end. Its general appearance is shown in Fig. 1. The "egg" is attached to an air-pump, and the two brass rods which run into the interior of the vessel are connected with the terminals of an induction coil. If now the current be turned on, before working the pump, a spark will flash between the two terminals in its ordinary zig-zag form. That is, if the distance be not too great for the spark to leap across. If the air-pump be worked slowly, a series of changes takes place. The spark first passes more easily, then loses its intermittent nature and forms a steady thread of light from one pole to the other; not so bright as the original spark, but of a beautiful purple hue. As the pressure is lowered by pumping out more air, the stream of light thickens out until it fills the whole vessel. After this a further lowering of the pressure causes the band of light to become narrower, and at the same time a strong difference is exhibited between the two terminals inside the "egg". The negative end, or *cathode*, is entirely surrounded, and clothed, so to speak, in a sheath of blue light. Outside this sheath comes a gap, and beyond this again a spindle of reddish purple light extending right up to the positive terminal or *anode*.

In the development of the Crookes' tube, the most interesting part of the luminous egg is now the pale sheath around the cathode. The spindle of deeper coloured light has many beautiful and interesting properties, amongst others the way in which it lies in striæ or bands of light alternating with dark bands. With these we have no especial concern here, so we shall simply study the effects close around the negative pole.

Neither the electric egg nor the ordinary air-pump is very satisfactory when we get to higher vacua than the ones described thus far, but with a Geryk air-pump and a suitable vessel of blown glass with platinum terminals fused solidly through its ends, the discharge may be studied much farther. For an investigation of the discharge through very high vacua some form of mercury pump such as is described in Chapter VI., Pt. II., will be required. Such pumps, although very useful to an X ray worker who possesses some slight skill in glass-blowing as explained later, are not at all essential, and therefore it is unlikely that the larger number of those who read this book will be able to carry out these experiments for themselves.

Suffice it to say then that as the pressure diminishes inside the glass vessel, the pale sheath of light begins to draw away from the cathode, leaving a dark space inside it. Fig. 2 shows the most convenient form of vessel for exhibiting this phenomenon. The main tube lies between the two platinum terminals marked respectively + and −, and it is within this tube that the light and dark spaces are to be seen. The side tube leads to the air-pump. The upper two-thirds of the tube show the purple spindle breaking up into striæ, whilst around the cathode marked − is the pale sheath of light. Within the sheath, at the zone indicated by the arrow head, is the dark space.

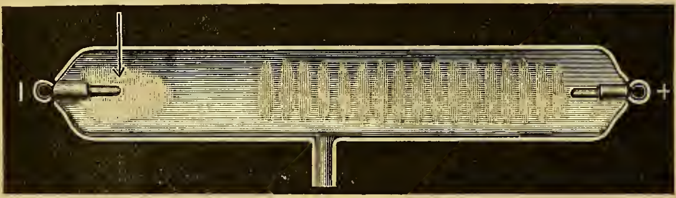

Fig. 2.—Discharge through Partial Vacuum.

As the pressure is further diminished, the dark space becomes wider, and soon afterwards the blue light dies away; and instead of the *air* within the tube giving light, the glass itself begins to glow with a golden yellow fluorescence. This shows first in patches, then as the blue light vanishes entirely, the yellow fluorescence gives a steady glow in some definite part of the tube, which varies according to the position and shape of the platinum terminals.

When the vacuum has arrived at this last state, the tube is a form of Crookes' tube, and what little air it contains behaves under the influence of electrical excitement in a different way from ordinary gaseous air.

To understand this difference we must know something of the kinetic theory of gases. By this theory " a gas is supposed to consist of a great number of molecules moving with great velocity,"[1] but the number of molecules, even in a very small space, is so enormous that none has to travel very far before colliding with another. The average distance which a molecule travels under a given pressure is spoken of as the *mean free path* at that pressure.

If air be pumped out from a closed vessel, or in other words, if a large number of molecules be removed, then the mean free path of those which remain will become greater. If we continue pumping long enough we shall eventually leave so few that the mean free path will be as large as the length of the vessel. In this case the molecules will travel from end to end with no other collisions than their encounters with the wall of the vessel. When a gas has been reduced to this state it is spoken of as radiant matter, or matter in the *radiant state.*

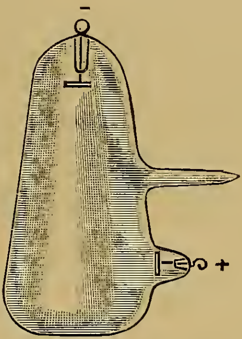

FIG. 3.—Crookes' Tube.

A Crookes' tube is essentially a closed glass vessel furnished with two electrodes or metallic connections with the outside,

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[1] Clerk Maxwell, *Theory of Heat.*

and containing air or some other substance in the radiant state. Such a tube is shown in Fig. 3.

If the terminal marked –, known as the cathode, be connected with the negative terminal of an induction coil, and the + or anode with the positive terminal, molecules will be flung off violently from the cathode, and as they meet with no other particles they set up a bombardment on the glass at the far end of the tube. Under the influence of this bombardment the glass gives out a light whose colour varies with its chemical composition. With ordinary glass the colour is yellowish.

By enclosing various substances in the tube, so that they come under the influence of this bombardment, many beautifully coloured fluorescences are obtained. Sir William Crookes examined these colours spectroscopically, and found that he could detect the most minute traces of impurity in many substances which had not hitherto come within range of spectroscopic examination.

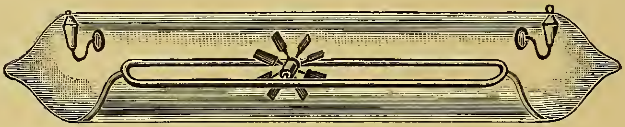

FIG. 4.—Crookes' Experiment.

Crookes' theory of radiant matter was very much questioned by continental physicists, who preferred to consider that the energy emanating from the cathode was some form of ethereal disturbance to which they gave the name of *cathode rays*.

To substantiate his theory, Crookes performed a number of remarkable experiments, three of which are described here as they help to throw light on later work.

A tube was constructed somewhat in the form shown in Fig. 4. The anode and cathode were situated so that a straight line joining their centres was well to one side of the tube. On the other side was placed a pair of glass rails. Running freely on the rails was a wheel each of whose spokes carried a mica vane. To perform the experiment the tube was set so that the rails were accurately horizontal. On passing the current the radiant matter from the cathode struck the vanes lying uppermost on the wheel and caused them to move, thus making the wheel run along the rails towards the anode.

The second experiment, which is interesting to ray workers as showing that the radiant matter stream travels in straight lines from the surface of the cathode, is shown in Fig. 5. A mica cross was inserted in the tube so as to interfere with the stream of molecules; the result was that when the tube was excited the glass fluoresced where the stream was able to reach it but not where the mica cross intercepted the molecules, thus throwing a shadow as shown in the figure.

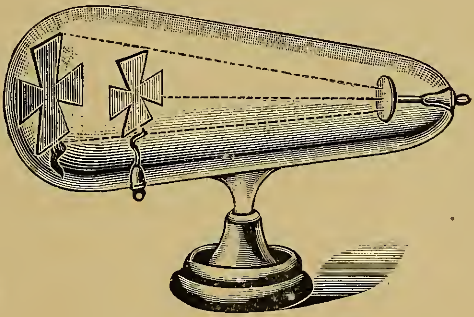

FIG. 5.—Crookes' Experiment.

The third experiment shows how the molecular stream may be focalised on a point by means of a concave cathode. A bulb was blown containing at one side a concave aluminium cathode. At the centre of curvature of the aluminium was placed a little ball of platinum, connected by a platinum wire with the outside of the bulb and forming the anode. On exciting such a bulb the concentrated bombardment of molecules flying off radially from the cathode had so great an action that the platinum became red hot.

During these experiments an event occurred which, seen by the light of later discoveries, shows how near Sir William Crookes was to discovering the phenomena which take place outside his radiant matter tubes.

In a paper read before the Roentgen Society on 11th January, 1898, by Mr. William Webster, the following passage occurs:—

"To Sir William Crookes we undoubtedly owe the fact that the X rays were ever noticed, for if he had not invented his tube, this society would not have been in existence. He informed me that during an experiment with a camera and one of his tubes he noticed, on developing the plates, that certain marks corresponding to his fingers appeared on the films, and thinking it was due to defective plates, returned them to the makers with some strong remarks. Now if he had only thought of the tube, Crookes would have been first in the field, for the experiment took place before Roentgen's discovery."

Whilst Crookes was striving to prove his radiant matter theory, Prof. Lenard was equally industrious trying to disprove it. In 1894, two years or so before the discovery of the properties of X rays, he discovered that under certain conditions some form of radiation took place outside a tube. Hittorf had already shown that if an aluminium cross be substituted for the mica one, shown in Fig. 5, no shadow is cast. Lenard, considering that the cathode rays, as he called them, would penetrate aluminium, made a radiant matter tube, in one part of which a thin sheet of aluminium was used instead of glass. He discovered that cathode rays were to be detected *outside* the aluminium.

One of the experiments of Crookes was to place inside his tube a phosphorescent screen which was lit up by the radiant matter. Lenard placed a similar screen[1] outside his aluminium "window" and found that it lit up.

Crookes' streams of radiant matter could be deflected by a magnet, as shown in Fig. 6. The stream was first passed through a small hole in a mica plate and then allowed to move longitudinally along a phosphorescent screen. This screen marked out the track of the molecules by a bright streak. A magnet, placed as in the figure, deflected the streak. Lenard showed that the illumination of a screen placed outside his "window" could also be deflected by a magnet, though not to the same extent.

We need not follow the controversy farther. The general opinion amongst English physicists is that the bombardment of the aluminium plate has some action on the molecules of air on the other side of the plate.

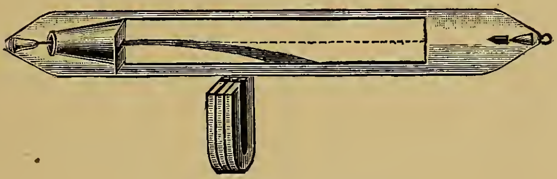

FIG. 6.—Crookes' Experiment.

Lenard's experiments are interesting to the radiographer chiefly as leading to the first observations of rays outside a Crookes' tube.

About the same time another worker, Prof. Herbert Jackson, of King's College, had designed a tube destined to play a great part in X ray work. To quote again from Mr. Webster's paper :—

"Prof. Jackson made his first focus tube in 1894. . . . It is exactly the same form which is now used throughout

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[1] Crookes' fluorescent material was zinc sulphide or calcium sulphide. Lenard's was pentadecylparatolyl ketone. Neither of these substances is sufficiently sensitive for X ray work.

the scientific world, and it was during that year that he was actually experimenting with phosphorescing small screens made with potassium platino-cyanide crystals when he demonstrated the fact that wood, vulcanite and allied materials were pervious to certain rays produced by the electrical bombardment in this tube, and also that metals were impervious to certain rays, but pervious in varying degrees to others. I have not only this evidence from Prof. Jackson's own mouth, but also from others who knew of his experimental work."

This brief sketch of the experimental work leading up to Roentgen's discovery shows that things were fully ripe, and the X rays could not hide themselves much longer from human knowledge. One day Prof. Roentgen saw the shadow of a skeleton hand on a fluorescent screen, and the great discovery had been made.

CHAPTER III.

THE DISCOVERY.

On 8th November, 1895, Prof. Wilhelm Conrad Roentgen, working in the Institute of Physics in the University of Würzburg, in Bavaria, first saw a fluorescent chemical glow under the influence of the X rays. In December of the same year he read a paper to the Würzburg Physico-Medical Society on "A new form of radiation". In the first two paragraphs of the paper he described his discovery as follows:—

"If we pass the discharge of a large Ruhmkorff coil through a Hittorf or sufficiently exhausted Lenard, Crookes or similar apparatus, and cover the tube with a somewhat closely fitting mantle of thin black cardboard, we observe, in a completely darkened room, that a paper screen washed with barium platino-cyanide lights up brilliantly, and fluoresces equally well whether the treated side or the other be turned towards the discharge tube. Fluorescence is still observable 2 metres away from the apparatus. It is easy to convince one's self that the cause of the fluorescence is the discharge from the apparatus and nothing else.

"The most striking feature of the phenomenon is that an influence capable of exciting brilliant fluorescence is able to pass through the black cardboard cover, which transmits none of the ultra-violet rays of the sun or of the electric arc, and one immediately inquires whether other bodies possess this property. It is soon discovered that all bodies are transparent to this influence, but in very different degrees."

In the few weeks which had elapsed between the original discovery and its announcement, Prof. Roentgen had made an enormous number of observations, so that the first paper, from which the above quotation is taken, contained a very large amount of information.

During this short time he had tested the transparency of a number of substances. He had discovered the photographic power of the rays, and had made photographs of various shadows; and he had made pin-hole photographs of his tubes, besides carrying out many experiments with the idea of elucidating various theoretical points.

Curiously enough the property which was destined to make the X rays so useful in surgery, namely, the different degree in which they penetrate flesh and bones, was only referred to in two short passages.

In paragraph 2 is the statement :—

"If the hand be held between the tube and the screen, the dark shadow of the bones is visible within the slightly dark shadow of the hand."

In paragraph 14 the following occurs :—

"Many shadow pictures, the formation of which possess a charm, I have observed—some photographically. For example, I possess photographs of the shadow of the profile of the door separating the room in which was the discharge apparatus from the room in which was the photographic plate; also, photographs of the *shadows of the bones of the hand,* of the shadow of a wire wound on a wooden spool, of a weight enclosed in a small box, of a compass in which the magnetic needle is completely surrounded by metal, of a piece of metal, the homogeneity of which was brought out by the X rays, etc."

Although the original paper contained so large an amount of information, it suggested many lines of investigation which were taken up by experimenters throughout the civilised world. The earliest work done in this country was in the way of photography. The English photographic newspapers, after a short interval of scepticism, published practical details, together with pictures of hands and other objects, thus bringing the requisite knowledge to many outside the scientific world, which first received accurate information through the pages of *Nature*.

Foremost amongst these periodicals were the *Photogram* and the *Amateur Photographer*. The former published a special number containing shadow pictures of such objects as a razor in its case, a set of metallic objects, such as a key and a pocket corkscrew photographed through a sheet of aluminium, and a frog, showing bones, by Mr. A. A. Campbell Swinton, and others by Mr. J. W. Gifford. The *Amateur Photographer* printed a hand and other objects by Dr. Slaby.

Such publications as these turned the attention of a large number of experimenters so strongly towards photography that the other method of utilising the rays seems to have been greatly neglected.

Roentgen's first experiments were made with a fluorescent screen of barium platino-cyanide, by means of which, as he tells us, he was enabled to examine the bones of his hand directly, and without taking the trouble of photographing them. This seems to have been overlooked; for within a few months of the original discovery the fluorescent screen was claimed as a new discovery by Salvioni and others.

Edison examined the fluorescing effect of the rays on a large number of chemicals, and came to the conclusion that the best substance with which to coat a screen was tungstate of calcium, but afterwards improved on this by using crystalline calcium tungstate, which contained in solid solution a little manganese tungstate. Mr. Herbert Jackson used the hydrated potassium platino-cyanide, which is more easily prepared in the pure state than the barium salt. Roentgen's original substance, however, has gradually reasserted itself.

It is very difficult to purify and crystallise suitably, but several makers now prepare it in such a state that it fluoresces more brilliantly than any other substance; and the modest 2 metres mentioned by Roentgen as the distance from the tube where fluorescence was still visible, has grown to 50 or 60 feet and more.

This increase in power is, however, due not only to the increased efficiency of the screens, but also to improvements in other apparatus, notably tubes. But before speaking of these improvements, let me quote another passage from Prof. Silvanus P. Thompson's inaugural address to the London Roentgen Society, in which he pointed out that the discovery of the X rays by means of the barium platino-cyanide screen was no haphazard thing, but something far higher. He said: "Lenard's success in bringing the cathode rays themselves to the outside of the Crookes' tube, and the existence of the long-standing dispute as to the nature of those rays, are two circumstances which might well stimulate other inquirers to examine further the phenomena attendant on electric discharge in high vacua. In 1895 fluorescent screens were not things likely to be lying about accidentally, even in a laboratory where Crookes' tubes were being used. Hence Roentgen's discovery cannot in any sense be called accidental; it was the result of deliberate and directed thought. He was looking for something—he knew not precisely what; and he found it. Fortunate the discovery may well be deemed, but not fortuitous."

As was told at the end of the last chapter, Prof. Jackson had been working with a special form of Crookes' tube, which has since become famous as the focus tube. He at once found the superiority of this form over the ones used by Roentgen, and thus enormously improved our power of using the X rays. The rays as originally produced travelled in straight lines, starting from many parts of a somewhat large area. When produced in a focus tube they start almost from a point, thus giving exceedingly sharp shadows. Further, the focus tube was more efficient, and, for a given expenditure of electrical energy, emitted the X rays in larger quantities than the older tubes.

This tube, in which the stream of radiant matter is focussed on a platinum plate, instead of being allowed to fall on the glass of the tube, is described on page 90 *et seq.* It may be considered as the greatest improvement which has been made in our methods of producing X rays. Apparatus has been made more powerful, and improved in mechanical details, but no great change has been made from Roentgen's original methods which can in any way compare with the introduction of the focus tube.

Before its introduction, so far as I can discover, no complaints had been made of X ray dermatitis. Indeed, Dr. Walsh has suggested that this peculiar form of skin irritation should be named focus tube dermatitis instead of the more commonly used name. At first the existence of this peculiar effect was greatly doubted, and any irritation reported was put down to electrical effects which might be caused by passing wires bearing the high-pressure current too near the skin of the patient. The fact has, however, slowly but surely asserted itself, that prolonged exposure to focus tubes strongly excited has an injurious action on the skin. This question has been investigated by many dermatological experts, especially by Prof. Elihu Thomson in America and Dr. David Walsh in England. In Dr. Walsh's well-known book, *The Roentgen Rays in Medical Work*, an exhaustive account is given of this peculiar action. It is, however, comparatively rare, and has had no effect in staying the rapid introduction of X ray apparatus into hospitals and consulting-rooms.

The first idea, at any rate of the general public, on hearing of Roentgen's discovery, was that its chief use would be the localisation of bullets, needles and foreign bodies generally.

This seemed so self-evident that the difficulty of localising a needle in a hand or foot is absolutely startling. The shadow is so elusive. Take for instance the radiogram of a foot shown in Plate II. The plate shows the view of the plantar surface. The mark of the needle's entrance was perfectly visible, but the needle itself could not be felt. A second radiogram taken from a different point of view showed that the needle was nowhere near the plantar surface.

In all localisation cases two photographs are necessary, and even then, without great precautions, very erroneous ideas may be arrived at.

Various kinds of apparatus have been designed to make work of this kind more reliable, but in most cases calculations of more or less complexity are needed. All difficulty has, however, been done away with by the carefully thought out system of Dr. Mackenzie Davidson published in the *British Medical Journal* of 3rd December, 1898. His system is stereoscopic. By means of a special apparatus he takes two radiograms from two accurately defined positions some few inches apart, and either examines the results through a stereoscope or makes measurements by means of an ingenious arrangement of silk threads. Some of the work done by its aid, such as the localisation of scraps of steel in the eyeball, may be considered as the highest point which has so far been reached in this direction.

More recently Dr. Rémy, of Paris, has invented a localising apparatus which also dispenses with the need for calculations. Instead of the silk threads, he uses steel pointers. Dr. Rémy gives these pointers the very apt name of "materialised rays," because they are used to trace out the paths of special rays. The name would apply just as well to the silk threads of the Davidson localiser.

On page 124 *et seq.* descriptions are given of both these instruments, and on page 142 various other methods for the rapid localisation of foreign bodies are described.

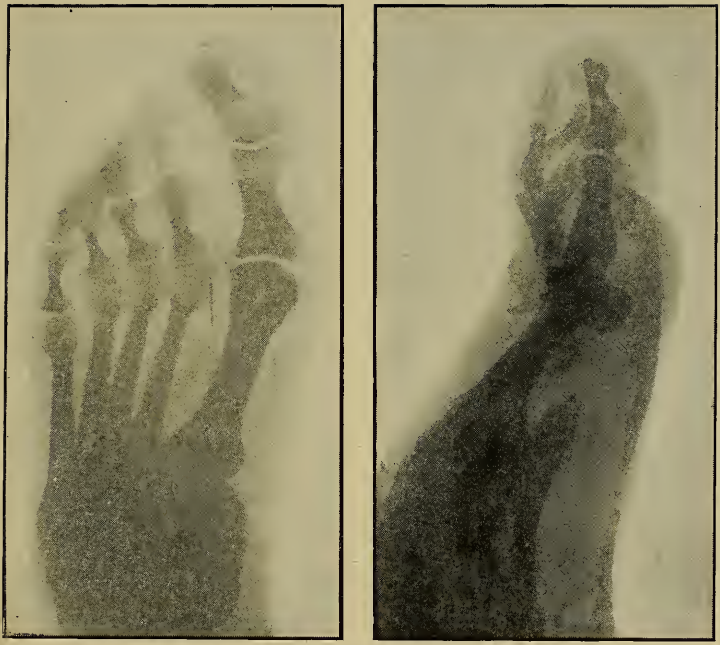

Plate II.—Needle in Foot.

While this development was approaching its present perfection, other workers were trying to discover the action of X rays on bacteria. The peculiar penetrative action of the rays would make them valuable aids to the physician if it could once be shown that they had a therapeutic effect. This was naturally one of the first ideas which occurred to physicians.

So far as the effects of the X rays on germ life are concerned, just sufficient results were obtained to suggest the possibility of further success, but not sufficient to justify great hopes. Sormani's early experiments (1896) in Italy showed no effect whatever on culture of pathogenic organisms; but later experiments, probably with more powerful apparatus, have shown that guinea-pigs inoculated with tubercle culture and exposed daily to the action of X rays showed very little disease at the end of six weeks, whereas animals similarly injured but not submitted to X ray treatment were described as showing abscess at the point of inoculation, enlarged glands, and general loss of condition. These experiments have given the same results in the hands of Fiorentini and Luraschi in Italy, and Lortet and Genoud in France.

On the other hand, many experiments have been carried out with the intention of helping diagnosis without therapeutic effects being observed.

So far as medicine and surgery are concerned, the history of X rays up to the present tells us that foreign bodies, even such as renal and vesical calculi, can in most cases be accurately localised and measured. That injuries to bones can be rapidly diagnosed, and that abnormal conditions of heart and lungs can be readily recognised. In later chapters more will be said on these subjects, but only in so far as they concern the actual X ray work. Those who wish for further information as to medical and surgical details are referred to Dr. Walsh's book which has already been mentioned.

PART II.

APPARATUS AND ITS MANAGEMENT.

CHAPTER I.

ELECTRICAL TERMS.

WHEN Prof. Roentgen made the discovery that a properly prepared screen would fluoresce under the action of X rays, he was using apparatus which had already been brought to a high state of perfection. Sources of power were ample. Electrical engineering had provided excellent primary and secondary batteries, and the streets of most English and continental cities had electric mains running side by side with the gas and water supplies. The induction coil was an instrument which had been brought from a mere toy to a highly efficient instrument, and Crookes' tubes were made and exhausted by many instrument makers.

Most of these instruments were, however, only used for special investigations, and their use was confined to quite a limited number of workers. As was to be expected, the great sphere of usefulness opened up by Roentgen's discovery brought a large amount of inventive talent to bear on this special class of electrical apparatus.

The instrument makers of the civilised world have produced so great a variety of coils, tubes and other accessories that it is almost impossible to give a full account of X ray apparatus.

In this section, therefore, no attempt has been made to cover the whole ground, but certain typical forms have been selected for detailed description. When these types are understood, no difficulty will be experienced in following out the action of their varieties.

An ordinary installation such as is supplied by most makers would consist of—

Battery,
Induction Coil,
Crookes' Tubes, with stand,
Fluorescent Screen,
Photographic Materials.

Of these, the first two are the most costly, and become the permanent parts of the installation. The battery is the source of electrical power, and the coil is the transformer by which the electrical power is "transformed" into the peculiar condition necessary for the proper exciting of the Crookes' tube. The current from the battery is, comparatively speaking, a large one at a low pressure. The action of this current on the induction coil supplies us with a comparatively minute current at an enormously high pressure. In a different class of installation the battery and coil would be replaced by some form of so-called static machine, which supplies the high-pressure current directly, so that no transformer is required.

In describing these instruments it is necessary to use electrical terms which are often puzzling to those who have no special knowledge of electricity. The explanations of the more common terms given in the following pages are not intended to be definitions, but rather general descriptions.

Electrical Quantities.—Electrical energy, like all other forms of energy, may be measured by reference to the fundamental units of length, mass and time, but as a general rule these units are unsuited for practical work. A practical system has therefore been generally adopted, and the quantities here given are the practical ones.

Electro-motive Force, also called *potential difference, electrical pressure* or *electrical tension*, is defined[1] as "that which moves, or tends to move, electricity from one place to another".

A very close analogy exists between the flow of water and the flow of electricity, and it is very easy, by following out the analogy, to gain more concrete ideas on the subject. If two cisterns be connected by a tube, the flow of water through the tube will be governed by the difference in level between the water surfaces in the two cisterns. The water will flow from the higher to the lower. In the same way electrical levels are spoken of as potentials; electricity will flow along a wire from a point at high to a point of low potential, and the flow will be caused by the difference of potential or electro-motive force.

The practical unit of electro-motive force is a *volt*, which is very nearly that of a Daniell's cell. The high-pressure discharge of the Holtz machine has an electro-motive force of about 53,000 volts.

Resistance.—"Substances that are very bad conductors are said to offer a great resistance to the flow of electricity through them. There is indeed no substance so good a conductor as to be devoid of resistance."[2]

Resistance then is the inverse of conductivity. In the water analogy the conductivity of the connecting pipe would be governed by its diameter. A very thin pipe would not allow so much water to pass in a given time as a thick one. It would offer a greater resistance. The unit of electrical resistance is the *ohm*. A column of pure mercury having a

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[1] *Elementary Electricity*, Silvanus P. Thompson, p. 155.

[2] *Ibid.*

cross section of a square millimetre and a length of 106·3 centimetres has an ohm resistance.

Current.—"The strength of a current is the quantity of electricity which flows past any given point of the circuit in a second."[1]

This is of course dependent both on the electro-motive force and on the resistance. Returning to our analogy, the quantity of water which will pass any section of the pipe in a second will vary firstly, with the difference between the levels of the two reservoirs, and secondly, on the width of the pipe. It will increase with the increase of difference between the levels, and decrease with the narrowing of the pipe.

The unit of current is the *ampère*, or that current furnished by a pressure of one volt through one ohm resistance. This leads directly to Ohm's law which is referred to several times in the description of X ray apparatus. The law is that the strength of a current varies directly as the electro-motive force and inversely as the resistance of the circuit. This may be conveniently expressed thus:—

$$C = \frac{E}{R}$$

where C is the current measured in ampères,
E is the electro-motive force measured in volts,
R is the resistance measured in ohms.

Quantity.—We shall not have much need of this expression in describing X ray work, as in most cases it will be sufficient for us to measure currents or "quantities per second". The practical unit of quantity is a *coulomb*. In a current of one ampère the electricity passes any given point of the circuit at the rate of one coulomb per second.

Capacity is another term of which we shall have very

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[1] *Elementary Electricity*, Silvanus P. Thompson.

little need. The capacity of a conductor or condenser is measured by the quantity of electricity required to raise its potential one unit. Our water analogy here is not quite so definite. The capacity of a cistern would be measured by the quantity of water required to fill it. To compare it with electrical capacity, we must imagine the cisterns to be infinitely tall so that water may be stored up to any height. The relative capacity will then depend on their area of cross section, or rather on the quantity of water which must be pumped in to raise the surface a foot.

Batteries.—The word battery as used in this book means any *chemical* apparatus by which a current may be generated. In the water analogy the battery would become a pump. The chemical energy of the battery is used up in maintaining the difference of potential between its two poles. The pump would be used to pump water from the lower into the higher reservoir, and thus maintain the difference of level which would otherwise be altered by the flow through the pipe.

Accumulator, Secondary Battery, Storage Battery.—These synonymous terms denote a type of battery which when exhausted may be renewed by passing a current through it, in the opposite direction from the current which it gives out when working by itself.

Capacity of an Accumulator Cell.—The word capacity is here used in a somewhat loose sense, and expresses the quantity of available electricity which may be stored. It is usually expressed in ampère hours. Thus a battery of six cells of a total capacity of 30 ampère hours will give a current of 1 ampère at 12 volts pressure for 30 hours, or 30 ampère at 12 volts pressure for 1 hour. The number of hours during which a current is supplied being found by dividing 30 by the number of ampères of current; and conversely the numbers of ampères of current being found by dividing 30 by the number of hours.

As a matter of fact, this capacity is not a perfectly constant quantity, as a battery discharging with a small current will continue working rather longer than the calculated time, whilst when discharging very rapidly it runs down in less time than would be expected.

Alternating Currents.—Certain dynamos supply a current which, instead of flowing directly from one pole to the other, changes its direction many times per second. Each pole becoming positive and negative alternately, such currents are known as alternating. A current flowing constantly in one direction is called a *direct* current.

Induction.—This term is used to denote certain phenomena which cannot be illustrated by the water analogy. Either an electrical charge or a current or a magnetic pole have an influence which they can exert at a distance. This influence is known as induction.

Magnetic Induction.—If a piece of soft iron be brought near the north-seeking pole of a magnet, it will acquire the properties of a magnet. The end nearest the original north-seeking pole will become temporarily a south pole, and the end farthest away a north pole. A simple proof of this is to suspend a tack from one end of a bar magnet. It will be found that another tack may be hung on to the end of the first, and so on until a chain of five or six is formed. On taking hold of the top one and removing the magnet, they will all fall apart, as they are no longer subject to magnetic induction. The space around a magnetic pole where its influence is exerted is called its *magnetic field*.

Electro-magnetic Induction.—This type of induction is of great practical importance. Both the dynamo machine and the induction coil depend upon it for their action.

Two experiments may be described which illustrate electro-magnetic induction :—

(*a*) If a magnet be thrust into a coil of wire, the ends of which are connected with a galvanometer, a momentary current will be found to pass through the coil. On removing the magnet another momentary current will flow in the opposite direction. That is to say, an alteration of the magnetic field in the region of the coil of wire has the power of inducing a current in that coil.

(*b*) A conductor carrying a current has an inductive effect on account of the magnetic field which is always developed in its neighbourhood. To show this, we fit up an apparatus according to the diagram (Fig. 7). B is a battery or other source of electricity whose poles are connected by means of a wire, part of which, F G, lies in a straight line. In this circuit the current may be started or stopped by means of a key at A. Lying parallel to the portion F G is another wire, D E, which forms part of an independent circuit which contains no battery, but has an instrument for detecting current electricity, *viz.*, a galvanometer, at C. If now the current is turned on at A, so that it flows through F to G, at the instant of starting, a momentary current will be induced in the parallel wire, running from E to D, or in the opposite direction from the first. On

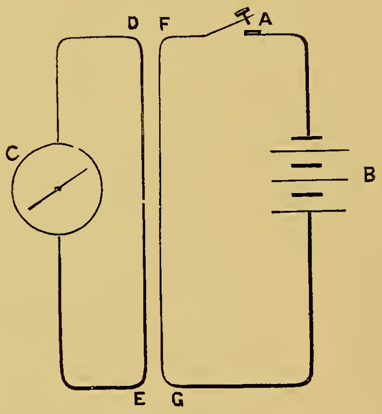

Fig. 7.—Diagram illustrating Electro-magnetic Induction.

stopping the current at A, another momentary current is induced, but this time running from D to E, or in the same direction as the original current.

Technically we speak of the circuit A F G B, which contains the source of power, as a *primary* circuit, whilst D E C is named the *secondary* circuit. Starting a current in the primary circuit is known as "making," and stopping it as "breaking". The current in the secondary circuit is called an *induced current.*

When we come to consider the amount of the induced current, we find that it is dependent on the following conditions:—

The distance between the primary and secondary wires—the nearer the two wires are together, the greater will be the inductive effect.

The strength of the primary current—the greater this current, the higher the inductive effect.

The suddenness of make and break.—In practice, as is explained in the chapter on "Induction Coils," it is easier to break the current suddenly than to make it suddenly. In either case, the more rapid the change and the greater will be the inductive effect.

The concentration of the magnetic field.—In the experiment under consideration the magnetic field is in air. Highly magnetic substances, such as iron, if placed in the neighbourhood of the wires, would considerably alter the magnetic field, concentrating the greater part of the field in its substance. This should be remembered in studying the action of the induction coil.

Electro-static Induction.—If two conductors, insulated from each other and from the earth, one of which has a charge, or is at a high potential, be brought close together without actually touching, the uncharged conductor will be influenced by the charged one. The effect of this influence is shown in the diagram (Fig. 8). The round conductor is supposed to have a positive charge, and, therefore, to be at a higher potential than the earth. Its effect is to induce a difference of potential between the parts of the other. The end (marked −) nearest the inducing conductor acquires a low potential, and the farthest end a high one.

If, next, the long conductor be connected with the earth by means of a metallic wire, or even by touching it with a finger, the earth and the conductor become electrically one. The conductor becomes negatively charged, whilst the earth receives the positive charge.

On breaking the earth connection the long conductor is left with a negative charge, which it retains when removed from juxtaposition with the original positively charged conductor.

Fig. 8.—Diagram of experiment on Electro-static Induction.

This principle is used in the construction of an induction machine, which is, roughly speaking, an apparatus which brings a series of conductors in succession close to one already charged, connects them to earth, breaks the connection, then removes them in turn, each with its induced charge—in this way obtaining a series of small charges.

Dielectrics.—The magnitude of an induced static charge depends not only on the conductors and their relative positions, but on the "*inductive capacity*" of the intervening substance. In Prof. Silvanus Thompson's *Elementary Lessons in Electricity*, he explains inductive capacity thus:—

"We have assumed up to this point that electricity could act at a distance, and could produce these effects of induction without any intervening means of communication. This, however, is not the case, for Faraday discovered that the air in between the electrified body and the conductor played a very important part in the production of these actions. Had some other substance, such as paraffin oil or solid sulphur, occupied the intervening space, the effect produced by the presence of an electrified body at the same distance would have been greater. The power of a body thus to allow the inductive influence to act across it, is called its inductive capacity." Later on he states: "Those substances which are good *dielectrics* are said to possess a high inductive capacity".

In statical machines the dielectrics generally used are glass or ebonite.

CHAPTER II.

SOURCES OF ELECTRICITY.

General Considerations.—In this chapter only those sources of electricity will be considered which supply currents of low electro-motive force, and which are therefore used in conjunction with an induction coil. A description of electro-static machines will be found in Chapter IV.

An X ray worker who uses an induction coil has a considerable choice of sources of power. If he use a dynamo machine, it may either be a small one, which he himself controls, or a large one supplying the town mains. If he elect to use batteries, he may either use primary batteries which, in most cases, burn up zinc as fuel, or secondary ones, which store up electricity received from some primary source.

He will be guided in his choice by such considerations as portability, cleanliness and general convenience. Thus, a secondary battery is at present almost universally used; it is portable, fairly clean and constant, but requires frequent recharging. If there be no means of recharging at hand, he may get over the difficulty by using primary batteries, but these are dirty, require frequent renewal of their working parts, and easily get out of order. The ideal arrangement is undoubtedly to have a supply from street mains, with proper regulating and measuring apparatus, together with secondary batteries for special work. In this chapter the practical working of these various systems is described.

Small Dynamos.—A dynamo electrical machine consists essentially of two parts:—

(*a*) A magnet, or set of magnets, which produce a strong magnetic field.

(*b*) A coil of wire (known as the armature), which rotates in this field.

This rotation sets up an alternating current in the wire of the armature, which may either be led away as an alternating current or rectified by means of a special piece of apparatus known as a commutator, thus forming a direct current. As a radiographer is seldom called upon to manage dynamos, only a few details of their structure need be studied here.

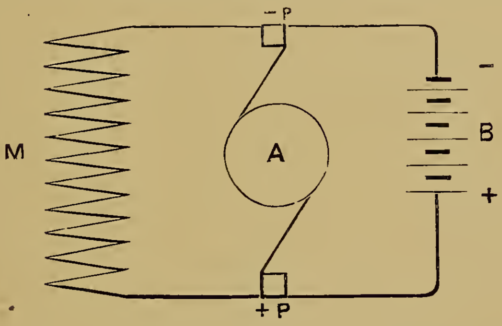

FIG. 9.—Diagram of Shunt-wound Dynamo.

Permanent magnets are scarcely ever used to produce the magnetic field of a dynamo, as electro magnets are more powerful and more manageable. The current which excites the magnets is usually supplied by the machine itself. When the machine stops working a certain amount of residual magnetism is left in the iron cores of the electro magnets. If this were not so, the machine would give out no current when restarted.

For small machines two methods of winding magnets are adopted—shunt winding and series winding.

A *shunt-wound* machine should always be chosen for X ray work, as an attempt to charge an accumulator with a series-wound machine sometimes leads to a peculiar reversal of the current with disastrous effects to the battery.

Fig. 9 shows diagrammatically the arrangement of the parts of a shunt-wound machine when charging a storage battery.

M is the coil of wire exciting the magnets, and is joined at each end to the poles, – P and + P of the armature A. B is the battery connected up to the poles of the dynamo so that it may be charged. Suppose that the machine were just starting, and that the residual magnetism in the magnets were very feeble. As the armature A started rotating, it would give a very feeble current running round the electro-magnet in the direction + P M – P. If the battery current were more powerful than the current of the dynamo, then instead of the battery receiving a current in the direction + P B – B it would itself give out a current. This current would divide itself up, partly running through the armature and partly through the magnets. That portion running through the magnets would be in the direction + P M – P, or in the same direction as it would be delivered by the dynamo. This would at once excite the magnets, the armature would deliver a more powerful current, and the pressure of the battery would be overcome.

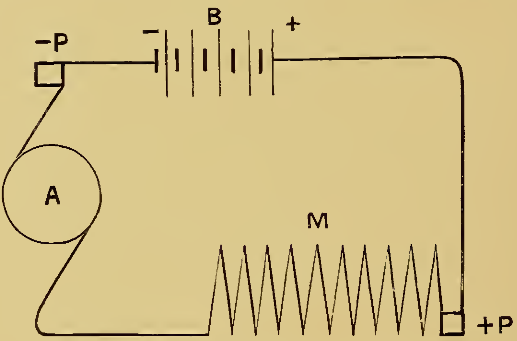

FIG. 10.—Diagram of Series-wound Dynamo.

A series-wound dynamo would be represented diagrammatically, using the same letters for similar parts, as in Fig. 10. A glance at the diagram will show that the current of the machine runs through the magnet in the direction A M + P, whilst if this were feeble, the battery current would run in the *reverse* direction. This would reverse the action of the machine and deliver a current through the battery in the wrong direction.

A small shunt-wound dynamo of very simple type is known as the Atlas No. 2, and when driven at a speed of 3,000 revolutions per minute, will give a current of 5 ampères at 10 volts pressure.

Although this would work a coil, if necessary,[1] it is far better to use it for charging up storage cells (see page 54). For those who live in a country place, where it is difficult to get batteries recharged, a dynamo of this kind is the most convenient instrument for supplying a current.

It may be driven by a small gas or oil engine of $\frac{1}{2}$ horse-power, or by manual labour. In the latter case large driving wheels are used, connected with the dynamo by a pulley. A special wheel is now made with a handle at each side so that two men may drive it. The crank shafts are geared so that the driving wheel makes from three to four revolutions for each turn of the crank shaft.

Seeing, however, that the operation of charging an accumulator if carried out efficiently and economically occupies about ten hours, manual labour is hardly adapted for the work. There are, however, circumstances under which it may be used with advantage, as, for instance, when very little X ray work has to be done. In this case the batteries may be charged thoroughly to begin with, and then recharged for half an hour or so after each operation.

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[1] Further remarks on the direct working of coils from dynamos are to be found in the Chapter on "X Rays in War".

A most ingenious arrangement was used by Major Battersby who had charge of the X ray apparatus in the Soudan campaign. He charged his batteries from a small dynamo driven by means of a tandem bicycle. This was mounted on a wooden framework, and the tyre removed from the back wheel. Two soldiers pedalled, and by means of a strap the power was transmitted from the back wheel of the bicycle to the machine.

Management of Small Dynamos.—Should a small dynamo "go wrong," it is best to call in the services of an electrical engineer, but there are several precautions which will often prevent trouble. Firstly, the machine should be kept as free as possible from dust or grit, especially the commutator and brushes. These are the parts most liable to go wrong. Both should be kept quite clean, so that each metallic section of the commutator may make a good connection with the brush as it passes. Secondly, in working the machine it will be found that there is one position of the movable brushes where the best effect is produced. This should be found by means of one of the measuring instruments described on page 39, and when once found the brushes should be clamped in position, and the machine, in all future work, should be run at the same speed. Thirdly, a small dynamo, when used for working the coil directly, should not be allowed to remain idle too long, or it will refuse to work, because the magnets will have lost all their residual magnetism. When used for recharging a battery, this will not matter, as the battery itself will excite the magnet sufficiently to start the machine.

If the machine refuses to work, a primary battery may be connected with the terminals, + to + and − to −. After allowing the current to run for a little while, the battery may be removed, and on starting the machine it will at once give a current and rapidly reach its full power.

Electric Mains.—When an electric supply is laid on to the house or institution in which X ray work is to be carried out its utility varies according to whether the supply is continuous or alternating. If the latter, the difficulties to be overcome in using it are considerable.

Where a continuous supply is available, it may be used directly in a stationary apparatus, or indirectly to charge the batteries for a portable installation.

The current is, however, at too high a pressure to be used in either way, and, except when working an electrolytic break (see page 76), it must be greatly reduced.

In the majority of cases the pressure is 100 to 200 volts, and this for average work, whether for charging batteries or working a coil, must *generally* be reduced to about 15 volts.

This is usually done by inserting a resistance, that is, by making the current flow through some substance which does not conduct freely, before it comes to the coil or battery. Various simple methods of inserting resistances when charging batteries are described on page 54, but where a coil is to be worked directly from the mains, it is advantageous to have some arrangement by means of which the supply can be accurately regulated and measured.

Rheostat.—This instrument, which is used for regulating currents, is best understood by referring to one of its earliest forms. This consisted of a long thin wire of German silver, wound in many coils round a cylinder of ebonite, and a movable key which could be made to press on any part of the wire. The total resistance of this wire being governed by its length is considerable. When using such an apparatus, the current from the main is passed in at one end of the wire and out again through the travelling key, which runs upon it. By moving this key along the bobbin, the current may be caused to pass through just as much of the resistance wire as is wished. A diagram of the arrangement by which the current is made to pass through half the resistance of a rheostat, before being used for charging a battery, is shown in Fig. 11.

The terminals of the main current are marked respectively M + and M –. Let us suppose that the difference of potential between the point M + and the point M – will be 200 volts. Acting against this pressure is the battery whose electro-motive force we may consider to be 12 volts. If now we take any section of the circuit connecting M + and M –, the fall of potential in that section, *i.e.*, the electro-motive force between the ends of the section, will be proportional to its resistance. Further, if the resistance of the portion of the rheostat in circuit (r) be nine times the effective resistance of the battery, the electro-motive force between the ends of r will be $\frac{9}{10}$ of 200 volts, or 180 volts, and that acting on the battery $\frac{1}{10}$ of 200 volts, or 20 volts, which is sufficient to overcome the opposing force and to charge up the accumulator. In practice the rheostat is always connected with measuring instruments, so that no calculations are required, the rheostat being adjusted until the desired current passes.

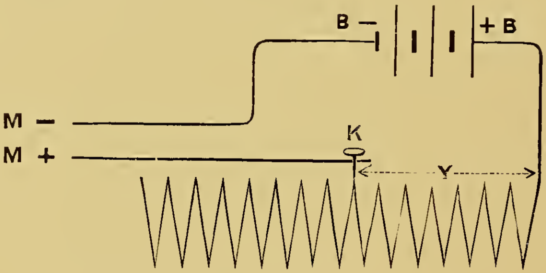


FIG. 11.—Diagram showing Action of a Rheostat.

Rheostats are made of various forms, but are practically all the same in principle.

Switch-boards.—This is the name given to a compendium of apparatus, which usually contains a rheostat or other changeable resistance, together with measuring instruments, and a switch for turning the current on and off. These, with other accessories, such as lamps, are mounted on a board, which is permanently fixed to the wall of a laboratory or working room.

Many forms of switch-board have been designed for X ray work, and are kept in stock by instrument makers; but any electrical engineer will readily design and fit up such an apparatus at no great expense. The most costly part will be the measuring instruments—voltmeter and ammeter—which will cost about £2 10s. each, and the rheostat, which, if accurately made, will cost £2 or £3.

Measuring Instruments.—When a secondary battery is being charged, or when its store of energy is being used to work a coil, or indeed in any case where electricity is being used, it is most important that the operator shall have some means of measuring the current.

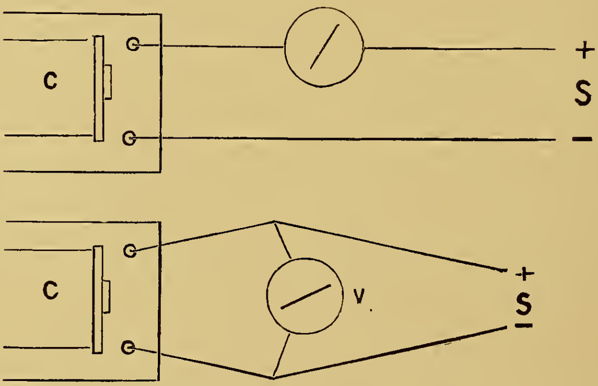
Unfortunately this is not always possible, as is explained later on in the section dealing with "Induction Coils," but there are two instruments named the voltmeter and the ammeter which are indispensable to the radiographer.

The voltmeter measures the *pressure* of the electricity in volts, and the ammeter measures the *current* in ampères.

Each is a galvanometer, and depends for its action on the fact that a magnetic needle tends to set itself at right angles to a wire bearing a current. This motion of the needle is hindered by a spring. The greater the current which is passed through the wire and the greater will be the angle through which the needle is deflected against the opposition of the spring. Thus the deflection of the registering needle in either case will depend on the *current* which is passing through the wire.

The difference in design between the two instruments is such that the current allowed to pass through the ammeter is either equal or proportional to that in the circuit to be tested, whilst the current passed through the voltmeter is proportional only to the pressure between two given points in the circuit.

The *ammeter* is an instrument in which the coil of wire has a very low resistance, so that the current in a circuit may pass through it without diminution, and it is always for the purposes of X ray work placed *in series* with the general circuit. This arrangement will be understood by reference to Fig. 12, which shows diagrammatically the connections between some source of power, such as a battery or dynamo (*S*), and an induction coil (*C*). The main current runs through the ammeter (A), and its quantity may be read off by the position of the needle on the scale.



Figs. 12 and 13.—Method of connecting Ammeter and Voltmeter.

The *voltmeter* on the other hand has a coil of fine wire offering great resistance to the passage of the current, and is placed in *parallel*, as shown in the diagram (Fig. 13).

The current has thus two alternative circuits, and the quantity passing through each circuit is inversely proportional to its resistance; but since the resistance of the voltmeter is exceedingly high when compared with that of the coil, it follows that the current passing through the voltmeter is exceedingly small. So small that the small quantity which it takes from the induction coil may be ignored. On the other hand, the difference between the resistances of the coil and voltmeter is so great that any alteration in the resistance of the coil will make no appreciable difference in the quantity going through the meter. Under these circumstances, the only condition which will alter the *current* through the meter is the pressure at its terminals, so that this current, and hence the pressure, may be measured by the deflection of the needle.

This explanation of the difference between the two instruments will also explain the difference between the ways in which they should be connected with the apparatus.

They are made in all sizes, but for work with a coil up to 18 inches air-spark, instruments reading to 25 volts and 30 ampères are sufficient. They are often sold mounted together on one stand.

Transformers.—The method of lowering the electro-motive force by means of resistances, described on page 37, is a very wasteful one, as the energy consumed in overcoming the resistance is very much greater than that used in working the coil or charging the battery. A more economical method, so far as electrical energy is concerned, is to use a transformer. This instrument will be readily understood by reference to the earliest methods of transforming high- to low-pressure currents. Instead of expending a large part of the energy in overcoming resistance, the current was used to turn an electro-motor designed to take the high-pressure current. The electro-motor was attached to a dynamo designed to give out a low-pressure current when worked at the speed of the electro-motor. As each of these two instruments had a very high efficiency, a small current at high voltage was effectively *transformed* into a large current at low voltage.

A modern transformer, for direct current, is merely an electro-motor and a dynamo machine in one. Seeing that a dynamo is a reversible machine, which can itself act as an electro-motor, it will be understood that by winding two coils of wire, or rather two systems of coils, on the same rotating shaft, a combined motor and dynamo, or, in other words, a transformer, may be made. Instruments of this class are made specially for X ray work by several firms. One type is made to take a current of 1¼ ampères at 200 volts, and give out up to 10 ampères at 16 volts.

Unfortunately the increased economy of current is more than counteracted, except where the X rays are used very largely, by the cost of the instrument, which is somewhere about £20.

Alternating Supply.—The street mains of an alternating supply carry a very high-pressure current, which, before entering a house, passes through a transformer, which reduces the voltage without rectifying the direction of the current. No great success has been achieved by using this directly on a coil, though there are several specially designed coils on the market, which are intended to take an alternating current. Their special peculiarity is usually a rather complex form of contact breaker.

It need hardly be stated that an alternating current is useless for directly charging a battery.

The only way to use the general supply is to attach an electro-motor, coupled by belting, with a low-pressure dynamo, thus transforming our electrical into mechanical energy, and using the latter to produce a low-pressure direct current such as we require. The apparatus is, of course, costly, and it is doubtful whether there is anything to be gained by using an electro-motor in preference to a gas engine.

Wherever there is an alternating supply laid on to houses, there is pretty sure to be some means, within reasonable distance, for charging batteries at small cost.

Although the alternating current has such serious drawbacks for ordinary work, it is quite possible that we may soon have such improvements in the use of the Tesla apparatus and X ray tubes worked from it, that good work may be achieved by its use. The Tesla apparatus is worked by means of an alternating current.

At present, however, all the best work is done either with an induction coil or with a Wimshurst's or Holtz's statical machine, and the general practitioner, or any other worker who has no time for research, is strongly advised to adhere to the line which has been most fully explored. If he should have an alternating current supply entering his house, he will usually save time and money by leaving it severely alone, and adhering to the use of batteries.[1]

Primary Batteries.—In the first paragraph of this chapter primary batteries were described as being dirty and troublesome. Nevertheless, there are occasions when they become a necessity, hence they merit a few words in any work on X rays.

The principle on which they all work is illustrated by the simple voltaic cell, in which a plate of zinc and a plate of copper are immersed in dilute sulphuric acid. *If the zinc be absolutely pure*, no chemical change will take place until the two plates are connected by a piece of conducting wire. As soon as the connection is made, an electric current will flow through the wire from the copper to the zinc, and back through the acid electrolyte to the copper. At the same time, torrents of hydrogen gas are liberated from the copper, rising

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[1] It is possible to rectify an alternating current by cutting off all the current running in one direction. This is done by using an asymmetric cell. Several such cells have been investigated; a description of one will suffice.

Morgan and Duff immerse two plates, one of chromium and the other of platinum, in dilute sulphuric acid, and pass the current through the cell thus formed. When the platinum is the anode, the current passes freely, but when the chromium is made anode no current passes. Such a cell will stop any current, up to 75 volts pressure, which runs through from chromium to platinum whilst allowing the reverse current to pass.

through the acid and escaping. If we note the defects of this primitive arrangement, and the general lines which inventors have followed in remedying them, we shall be in a position to understand the better forms of cell without detailed description.

(*a*) If impure zinc is used, what is known as *local action* takes place, the zinc dissolving rapidly in the acid and liberating hydrogen, thus wasting both the zinc and the acid; and as it is exactly this reaction which supplies the energy for working the cell, we have a rapid loss of fuel. Local action depends on the presence of small particles of iron or some other metal in the zinc, each particle forming a little cell on its own account. It is readily overcome by the disagreeable operation of amalgamation, or covering the zinc with a coat of mercury. The mercury will dissolve pure zinc, and thus the surface exposed to the action of the acid will be homogeneous, and not liable to local action. A dish large enough to hold the zinc plate is partly filled with dilute sulphuric acid, and a little mercury poured in. The zinc plate is dipped through the acid until it touches the mercury. This soon spreads over the surface of the zinc, forming a bright patch, which must be gradually rubbed over the whole surface with a piece of rag wrapped round the end of a stick.

Prof. Lewis Wright gives the following advice as to amalgamating zinc: "The trouble can be largely reduced, compared with what most people find it, by the simple expedient of using *plenty of mercury* in the process, which costs no more in the long run. The zincs should always be cleaned before amalgamating with soda and then rinsed if new and greasy; with dilute sulphuric acid and a fairly hard brush if black and corroded. Then pour a good quantity of mercury into a shallow basin, and some diluted sulphuric acid (1 part in 6 to 10 of water, or what is used in the cell will do) over the mercury. Introduce the zinc rod or plate into the acid, turning well about, then into the mercury, and 'lead' the latter over the zinc with a stiff brush till the whole surface becomes silvery white. When all is well coated, the zinc should be well rinsed with water, quite free of the acid, after which superfluous mercury should be brushed off into another basin or saucer with a rather stiff hog-hair brush. If much amalgamation has to be done, it is well to rub a little oil or vaseline over the fingers first to prevent the acid affecting the skin."

All primary batteries in which zinc is used will need this operation, which must be repeated from time to time.

(*b*) The hydrogen liberated from the copper plate does not at once rise through the liquid, but much of it adheres to the plate which has the effect first of increasing the resistance to the flow of electricity through the cell, and secondly of entirely altering the nature of the cell. Instead of a plate of copper and a plate of zinc, a great part of the cell consists practically of a plate of zinc and a plate of hydrogen.

Hydrogen and zinc form a cell which gives a current in the reversed direction.

Since the current is proportional to the electro-motive force, and inversely proportional to the resistance, both these actions of hydrogen gas tend to lower the current—the one by increasing the resistance and the other by lowering the electro-motive force.

The remedy for this action—known as *polarisation*—is usually a chemical one; and in all zinc batteries which are of any use for X ray work, it consists of immersing the plate from which the hydrogen is disengaged in some oxidising liquid, such as nitric acid or a solution of chromic acid. These burn up the hydrogen as soon as it is formed.

The difficulty of immersing the two plates in different liquids is overcome by placing one of them in a pot of unglazed earthenware, as is shown in Fig. 14, which represents a Bunsen cell. Inside the outer pot is a hollow cylinder of zinc immersed in dilute sulphuric acid; inside this comes the porous pot which contains a block of gas-carbon immersed in strong nitric acid.

(*c*) *Resistance.*—The relation between current, electromotive force and resistance, known as Ohm's law, and explained on page 25, is usually expressed by the formula $C = \frac{E}{R}$.

The electro-motive force is dependent on the materials of the cell, but the resistance is a quantity which decreases with the area of the plates and increases with the thickness of the layer of liquid between them. These facts should be borne in mind when determining the type of cell to be used.

The Bunsen Cell (Fig. 14) has already been described. The zinc needs careful amalgamation, and when working should be in *cold* sulphuric acid made up of 5 to 7 parts of water mixed with 1 part of strong acid.[1] If this acid effervesces in the cell, the zincs have not been properly amalgamated.

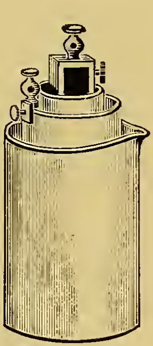

FIG. 14.—Bunsen Cell.

The nitric acid should be strong, and may be used so long as it continues to give off fumes. The chief difficulty with the carbon block is to make a good connection with the brass binding screw. Sometimes a hole is drilled into the top of the carbon and filled with lead, into which the screw is fixed.

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[1] Since heat is evolved when mixing sulphuric acid and water, the dilute acid must be prepared some time before it is required for use (see page 55).

Another method is to electro-plate the end with copper, but this soon corrodes, and sometimes finds its way into the battery, ultimately depositing on the zinc.

This cell, which gives an E.M.F. of 1·734 volts, is objectionable because of the nitrous fumes which it evolves, though it is fairly constant, and will work for some time.

As soon as the work is finished, the acids must be removed, taking care that no trace of nitric finds its way into the sulphuric, that is, if it be wished to use the sulphuric again. The different parts are washed, replaced in position, and the pots filled up with clean water. This keeps the zincs and carbons clean, and the porous pot in good condition.

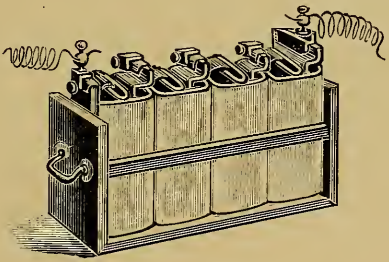

Fig. 15.—Grove's Battery.

Grove's Cell is usually made in a different shape from that of the Bunsen (see Fig. 15). This decreases the resistance by bringing the plates closer together. Instead of the carbon, a piece of platinum foil is placed in the nitric acid. This gets over the difficulty of the binding screw connection, and at the same time increases the E.M.F. to 1·956 volts.

As platinum is expensive, plates of gas carbon are sometimes substituted, giving a more efficient form of Bunsen cell of the Grove shape.

The management of the Grove is similar to that of the Bunsen cell.

The Bichromate Cell.—This is probably the best form for direct work, as it gives off no fumes, though the Bunsen would be better for charging an accumulator. Its two plates are carbon and zinc; there is no porous pot, and the liquid is a solution of bichromate of potash, or better, of chromic acid in dilute sulphuric acid (acid, 1 part; water, 7 or 8 parts; chromic acid to saturation). When several cells are used in series, some arrangement is generally supplied by means of which both carbon and zinc, or, at any rate, the zinc, may be removed from the liquid as soon as work ceases. This is very necessary, because the mercury coat affords no protection to the zinc from the effects of the acids. Such an arrangement is shown in Fig. 16, where all the zinc and carbon plates are fixed rigidly to a rack, which may be raised or lowered by a pulley.

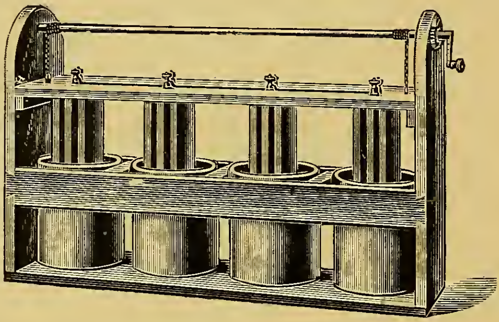

Fig. 16.—Bichromate Battery with Movable Plates.

In the ordinary form of the bichromate cell, the carbon plates remain permanently in the liquid, but the zinc may be raised by a brass rod sliding through the cover. This form is seldom used for driving a large coil.

The voltage of a single cell varies from 1·8 to 2·3 volts, according to the state of the liquid. When in good working order the bichromate or chromic acid solution should be of a bright orange colour. When it entirely loses this colour and becomes bluish, it should be changed.

Chromic acid may also be used in a "two-fluid" cell of the Bunsen shape. In this case the zinc is immersed in dilute sulphuric acid, whilst the carbon is placed in a chromic acid solution. The following mixture is recommended by Wright:—

Chromic Acid - - - - -	1 lb.
Potassic Chlorate - - - -	2 oz.
Sulphuric Acid - - - -	7 oz.
Water - - - - - -	40 fluid oz.

Mix the sulphuric acid with the water, and allow to cool, then add the other ingredients. This gives a cell as powerful as the Bunsen, but without its fumes. The chromic solution, however, is just as destructive to terminals as the nitric acid itself; care should accordingly be exercised in its manipulation.

Dry Cells.—Most primary cells are excited by some liquid reagent, though gases have been used, as in the chlorine battery, and solids, as in the silver chloride cell, and the various forms of so-called dry battery. Where batteries must be carried about, it is naturally a great advantage to possess some form in which the exciting material will neither spill nor get on to the terminals. Unfortunately, dry cells are not of sufficient constancy for any but the smallest form of X ray apparatus, and as the modern tendency is to use more powerful installations, the dry battery is very seldom employed. It consists of a closed cell whose outer casing is zinc. The positive pole is a rod of carbon, and the exciting material is a paste. One form is practically a Leclanché cell (zinc in ammonium chloride solution, and carbon in a composition of manganese dioxide and carbon), in which the liquid has been made into a paste with sulphate of lime. They are supplied ready for use, and when worn out are returned to the makers to be refilled.

Arrangement of Cells.—In providing a current for X ray work, one cell will never be sufficient by itself. The question, therefore, arises as to how the separate cells should be connected up. The current may be considerably altered by changes in the arrangement. The ordinary rule given in text-books is that the highest current is obtained from a battery when its cells are arranged so that the total internal resistance is as nearly as possible equal to the resistance of the circuit through which the current has to be passed.

In X ray work the safest method is to purchase large cells in the first place, thus ensuring small resistance in each cell; and to always connect them in series, *i.e.*, with the negative terminal of one cell attached to the positive terminal of the next, and so on. The pressure, or electro-motive force, so obtained will equal the sum of the pressures of the cells; thus eight Bunsen cells, in series, will give a pressure of 1·7 × 8 = 13·6 volts, which will work a 10-in. coil if the cells be large enough.

Secondary and Storage Batteries. — A storage battery, when charged ready for use, acts on exactly the same principle as the simple voltaic cell described on page 43. Each cell consists, theoretically, of a plate of lead (–), whose surface is in a spongy condition, and a plate of lead peroxide (+), both immersed in dilute sulphuric acid. The chemical reactions occurring in this cell, when it is being discharged, are rather complicated, but in the main the effect is to reduce the peroxide plate and oxidize the lead plate until both assume the intermediate form of litharge.

The peculiarity of this cell is, that by passing a current from a primary battery, or a dynamo machine, in a reverse direction through it, *i.e.*, by attaching the + pole of the dynamo with the + (peroxide) pole of the cell, we get it regenerated—that is, we reduce the litharge on the lead plate to spongy lead, and reoxidize that on the oxide plate to peroxide. Other reactions which take place during the discharge or regeneration of the cell will be mentioned later.

The earliest patterns of the cell were made by immersing two large sheets of lead in dilute sulphuric acid and passing a current, for an hour or two, through the electrolytic cell so formed. This would slightly alter the surfaces of the plates, and when they were connected through a suitable resistance, a small current would flow in the reverse direction from that originally supplied. This current was allowed to discharge itself, and then the dynamo applied again, but this time charging it in the opposite direction. After the cell had been thus charged and discharged many times in opposite directions, it was said to be "*formed*," and could be used as a secondary cell of some capacity.[1]

An obvious improvement on this long and troublesome method of forming a cell was to coat the plates with either litharge, lead peroxide, or spongy lead before using them. One of the great advances in the manufacture of modern accumulators has been the improvement of these compositions or pastes.

When they were first used, great difficulty was found in making them adhere to the lead plates, and various devices were resorted to. A modern battery plate is usually made up of a leaden framework or "*grid*" similar to the wax of a honeycomb, excepting that each hole is square in section. The holes are filled up with the paste. To make a positive plate, a mixture of red-lead or litharge and dilute sulphuric acid is forced into the holes in the grid and slowly dried. When perfectly dry it is immersed in a strong clear solution of bleaching powder. This oxidizes it to lead peroxide, and saves the trouble of forming. A negative plate may be made by filling the grid with paste and reducing by electricity, or by filling with spongy lead.

Many kinds both of grid and paste are used, but as the practical management of all kinds of secondary battery is much the same, the above description may be taken as typical.

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[1] See note on "Capacity of Accumulators" on p. 26.

In the cells used for radiography, the capacity is about 6 ampère hours per square foot of area of the positive plates, so that to get a capacity of 30 ampère hours—and less would be inconvenient—the area of the positive plate must be 5 square feet. An ordinary cell, therefore, contains several small positive plates connected together and alternating with several negative plates. Further, if one side of a positive plate reduces or oxidises more rapidly than the other, it is apt to twist, so that it is usual to arrange the plates so that each positive has a negative on either side of it, thus requiring one more negative plate in each cell than there are positives.

The type of cell to be selected for X ray work will depend on the class of work to be done. Where the batteries are to be moved about very much, one of the portable forms will be found most useful. These are generally made up in ebonite cells, enclosed in a case of oak or teak. The two most commonly used in England are Lithanode or E.P.S. (electrical power storage), batteries of six cells each, having a capacity of 30 ampère hours, and supplying a current at 12-volts pressure.

The Lithanode battery is completely closed in above with marine glue, excepting for stoppers, which may be removed to allow the escape of gas or to replenish the supply of acid. Such a cell is very heavy and liable to various accidents. A very little carelessness in transport—and there are many occasions when it has to be removed by unskilled servants—may lead to the cracking of a cell, which forms a leak, not only annoying on its own account, but apt to rot the wood of the case. I remember very distinctly a battery receiving a disastrous fall by the wood breaking at one of the attachments of the leather handle when it was being carried. One of the cells had sprung a leak some time previously and had been repaired by the makers, and most probably the strength of the wood had been impaired by acid.

It would be very much better, where batteries have to be moved about very much, to use two of a lighter type, of, say, four cells each. The slight extra trouble in coupling them would be more than compensated for by their gain in portability.

Reference to this subject will be made when considering practical installations (page 135). For stationary apparatus, where batteries are used, and where they may be charged *in situ*, it is far better to have separate open cells, which may easily be examined at will, the only drawback being the effect of evaporation.

The E.P.S. Company supply a battery of six cells, lighter than the one last described; moreover, the acid and plates are easier to examine, as each cell is simply covered by a wooden lid, the whole six being enclosed in a teak box.

Management of Secondary Batteries. — The chemical changes which take place in a battery during charge or discharge are not without their mechanical effects. The manufacture of plates has reached a high pitch of perfection, and so long as they are used carefully and intelligently, they will give excellent results, but as soon as they are subjected to strains which they are not designed to withstand, the mechanical effects begin to assert themselves.

The chief of these effects is alteration in the shape of a plate. This may be caused by too rapid charge or discharge. The first is apt to heat the battery and help the disintegration of the plates, and the second may cause "buckling" or twisting. It must be remembered that the plates are very close together, so that a twist may easily cause them to touch one another.

If a battery be allowed to completely discharge, it will begin to disintegrate, so that all batteries, whether in use or not, should be charged up from time to time. There is always a certain amount of electrical leakage, so that a battery left to itself will gradually "run down".

The best method of testing a battery's condition is by means of the voltmeter. The voltage changes with the state of its plates. When it is freshly charged, each cell has a pressure of a little over 2 volts (about 2·2). On discharging, either by being left to leak by itself, or by normal use, it rapidly sinks to 2 volts. This E.M.F. it retains during discharge for a considerable time, and so long as each cell when tested registers 2 volts, it may be considered efficient. When it has discharged as much as is safe, the electro-motive force again falls to about 1·8 volts, and the battery should be *at once* recharged.

For testing each cell separately—and this is the safest plan—a small voltmeter registering electro-motive forces up to 3 or 4 volts is the best: it costs about £2. When a voltmeter is used in the ordinary course of work, it is customary to measure the total E.M.F. of the battery, thus using an instrument capable of registering 20 or 30 volts. In such a case the battery should not be used when the number on the voltmeter falls below twice the number of cells.

Charging Batteries.—Seeing that a secondary battery is a somewhat expensive portion of an X ray outfit, and that its period of usefulness is greatly dependent on the care with which it is used, a careful study of the precautions necessary both in charging, discharging and general management will amply repay the radiographer. When purchasing a battery, the buyer should always make sure of as many details as possible with regard to the current which is most efficient in charging, and the current which it is best adapted for supplying. As a rule, either the maker or dealer from whom it is purchased can supply a tabulated form giving size and number of plates, capacity in ampère hours, normal charging and discharging rates in ampères, together with such other details as the weight and size of the battery.

To follow out in detail the process of charging, the first consideration is the state of the "*electrolyte*," in this case sulphuric acid.

The *acid* should be free from arsenic, and, as sulphuric acid is very cheap, and very little is required, the best brimstone sulphuric acid should always be used. One part of the strong acid is poured into seven parts of water, in a stoneware jug and well stirred.[1] It is allowed to stand until quite cool, when some sediment may have settled. The specific gravity of the cool acid will now be about 1·190.

This density of the acid is very important, as variations from the above strength make a great difference in the resistance of the cells, and therefore introduce the possibility of heating during work. Every medical man is well acquainted with the use of many forms of hydrometer, though the ones which he uses for such purposes as taking the density of urine are not graduated to sufficiently high gravities for this work. A special one may be purchased at a small cost graduated from 1·100 to 1·300. It is usually made of a flattened form so that it may be introduced into an open cell.

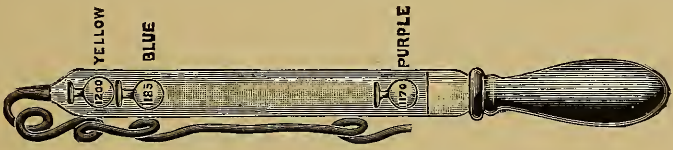

FIG. 17.—Hicks' Hydrometer.

A most ingenious hydrometer is manufactured by Mr. Hicks, for use with secondary cells. One form of this is shown in Fig. 17. The hydrometer consists of a flattened tube open at both ends to admit the acid, and containing three coloured glass bulbs or floats. The upper one, purple, marked 1·170, will float as soon as the acid exceeds that strength, the next will rise as soon as the acid exceeds 1·190, and the third when the gravity rises above 1·200.

The form shown in the figure is intended for use with the

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[1] Never pour the water into the strong acid, but always the acid into the water.

closed form of battery so much in favour at present. The flexible tube is passed into the interior of the battery, and sufficient acid sucked up by means of the rubber bulb to float one or more of the coloured beads.

Unless the battery has been transported from a distance, it will arrive ready charged, in which case the acid prepared above is only used for replenishing.

Should the battery be purchased dry, the plates must be just covered with the liquid before charging, the chief precautions being to see that the acid is quite cold and of the requisite strength.[1]

The next consideration is the actual charging. This may be done either from electric light mains, a private dynamo machine or primary batteries. The arrangement of the last has already been explained (page 49). The private dynamo will either have been purchased especially for this work, or will be one used for lighting. In the latter case it must be treated in the same way as a street main.

The two requirements are (*a*) that the battery shall be correctly connected with the source of power, and where this is variable, with measuring instruments; and (*b*) that the current shall be regulated to the correct extent.

With regard to the first, the negative pole of the accumulator must be connected with the negative pole of the supply, and the positive to the positive.

Should there be any doubt as to which pole is which, either in the case of the accumulator or the supply, the simplest way

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[1] Later on, in describing the operation of charging, the gravity of the acid is given as varying from 1·190 to 1·204. The Hicks' hydrometer can be supplied to measure these strengths accurately, but the one just described is very convenient, as the state of the electrolyte can be judged at a glance. If the acid has been correctly prepared, the purple bead will always float to the top. The middle one should not float until charging has begun. When the third floats the charging has gone as far as necessary, and any further current passed into the cell will be used up in decomposing the acid.

to find the direction is by means of pole finding paper. This may be purchased, or readily made by soaking a strip of white blotting-paper in a solution of sodium sulphate, coloured with either blue litmus or lacmoid, and drying. When required for use the paper is moistened and touched by two wires, one connected with each pole. The sodium sulphate will be decomposed with separation of sulphuric acid at the *positive pole.* The acid at once turns the litmus *red*, whilst the alkali developed at the other pole has no effect on the blue colour.

As to the regulation of the current. Where a switch-board with rheostat and meters is available, the matter is simple. The accumulator is connected up with suitable wire (14 or 16 B.W.G.), the rheostats turned to their highest resistance, and the current switched on. Next the rheostats are turned so as to gradually lower the resistance until the requisite current in ampères is registered on the ammeter. If this current has not been stated by the maker, a safe rule is to divide the capacity in ampère-hours by 10, and to allow 10 hours for complete charging. Thus an ordinary 30 ampère-hour accumulator should be charged with a current of 3 ampères for about 10 hours.

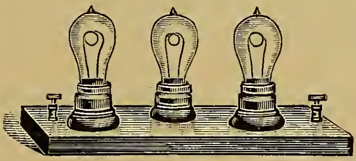

FIG. 18.—Lamp Resistance.

There are, however, cheaper and simpler means of reducing the current than rheostats. At one time water resistances were recommended, but nowadays incandescent electric lamps, suitably mounted, are generally used.

An electrical engineer should be employed to make the necessary arrangements. Three 16 candle-power lamps are placed in parallel so that the resistance may be $\frac{1}{3}$ of that of a single lamp. These should be arranged side by side on the wall, with two terminals and a switch.

A convenient arrangement supplied by several makers is shown in Fig. 18. Here the lamp resistance is mounted on a movable board, so that the only necessary fixture is a plug which the electrician will fix in the wall. He should of course be informed of the exact capacity of the battery, and the rate at which it is to be charged, so that he may insert a suitable safety fuse. To charge the battery from such a plug, a connecting wire is used similar to that used for reading lamps. Both wires are usually placed in one binding for the greater part of their length, their free ends being fixed to a flat piece of copper made in such a shape that it may be readily attached to the terminals of the battery. After testing for negative and positive poles, the plug should be marked so that it may always be replaced in the same position, and the copper attachments should be stamped, the one with a + and the other with a −.

As charging proceeds, various chemical changes take place in the cell. The alteration in the plates has already been mentioned. It is the change in the electrolyte, however, which gives us a clue to the state of the cell. The acid, which had at first a specific gravity of 1·19, gradually dissolves a certain quantity of lead, until its density has risen to 1·204. When it reaches 1·200, it becomes saturated with lead sulphate, so that it begins to appear milky, and when the hydrometer registers 1·204, the acid decomposes rapidly, giving off oxygen and hydrogen gases.[1]

If the charging current should be a little too strong, this disengagement of gas, or "boiling," as it is often called, begins to take place before the cell is fully charged, so that it should not be taken as definitely indicating that the work is complete.

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[1] See footnote to p. 56.

If the cells be open ones, a Hicks' hydrometer may be left in the electrolyte during the whole operation and examined from time to time. If they be enclosed in a box, the tube of the hydrometer (Fig. 18) should be introduced through one of the plug holes in the top, and a little of the acid sucked up from time to time into the tube by means of the ball, so that its density may be noted. The floating of the lowest ball indicates that the battery is fully charged.

It is advisable to allow the battery to stand for an hour or so until any gas adhering to the plates has been disengaged, and then to test each cell separately with the small voltmeter.

CHAPTER III.

INDUCTION COILS.

Ruhmkorff's Coil.—Medical men are well acquainted with the general appearance of the small coils used for producing the "faradaic" current; but as the large X ray coils are built up on the same principle as these small ones, it will be as well to consider their construction in detail.

On page 27 will be found a short explanation of the word "induction," together with descriptions of experiments on induced currents. In the same place the technical terms primary coil and secondary coil are defined. It is difficult to describe an induction coil without using technical expressions, but these are avoided, as far as possible, in this chapter. Where they become necessary they are used without explanation, and the

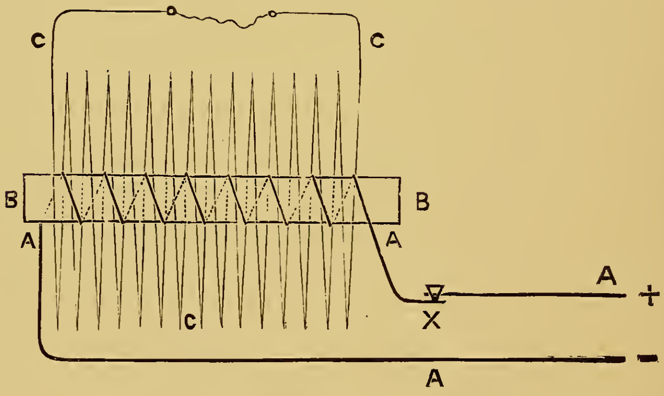

Fig. 19.—Diagram of Small Induction Coil.

reader is referred either to the chapter on "Electrical Terms," or to some elementary text-book on the subject.

The names of Mason and Du Bois Raymond are intimately associated with the earlier induction coils, but the form used in X ray work is usually considered as a development of Ruhmkorff's invention.

Figure 19 shows diagrammatically the construction of a small coil. A thick wire, A, A, A, A, capable of carrying a powerful current, is wrapped in a coil round a bundle of soft iron wires. Outside this, and carefully insulated from it, is a coil consisting of many turns of fine wire, C, C, C, each turn being well insulated from the next. The coil of thick wire, A, forms the primary, and the coil of thin wire, C, the secondary circuit.

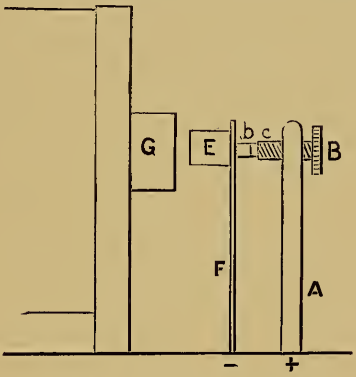

FIG. 20.—Mechanical Break.

In the primary circuit is a mechanical arrangement, X, for rapidly making and breaking the current. Many interrupters, as these arrangements are named, have been devised, and the chief will be described in a later paragraph. One of the oldest (Fiszeau's) consists of an upright bar, A (Fig. 20), connected with the positive terminal of the battery or source of power. The current passes up the bar, along a screw, B, which terminates in a piece of platinum, *c*. The platinum presses against another piece, *b*, so as to form electrical contact. The piece *b* is fixed to an upright spring, F, at the top of which is an iron weight, E. The current thus runs up A and down F. Thence it is led to the primary coil. G in the diagram represents the end of the bundle of iron wires. When the current passes, this bundle of wires becomes magnetised and attracts the iron weight, E. As soon as this moves towards G, it "breaks" the current by separating the platinum contacts *b* and *c*. As soon as the current stops, the "core" of iron, G, loses its magnetism, and the weight flies back under the influence of the spring, F, thus "making" the current. This alternate making and breaking goes on very rapidly. The speed at which it takes place, and the influence of the speed on the secondary current, is discussed later.

At the "make" a momentary inverse current is induced in the secondary coil which, for reasons explained later, is comparatively small and becomes suppressed, whilst at the "break" a powerful momentary direct current is induced, and it is this current which manifests itself by a spark passing between the ends of the secondary coil.

A further attachment is the condenser, consisting of a large number of sheets of tin-foil separated by layers of paraffined paper. The sheets of tin-foil are connected alternately with the upright (A, Fig. 20) and the spring (F, Fig. 20) of the contact breaker.

As the induction coil is one of the most important parts of an X ray installation, it will be described in considerable detail.

The Primary Coil.—In speaking of a dynamo machine (page 33), it was stated that the current is caused by the motion of a coil of wire in a magnetic field. In an induction coil the secondary effect is caused by altering the magnetic field whilst keeping the coils stationary. Hence it is necessary that the magnetic field caused by the primary coil shall be strong and concentrated, and shall change very rapidly with the make and break of the current. This concentration and strengthening of the field is secured by means of the iron core. As mentioned in the last paragraph, it is usually made up of fine iron wire. Such a bundle of wires magnetises and demagnetises more rapidly than a solid core of iron, hence giving very rapid alterations in the magnetic field.

In large coils, the primary consists of two or three layers of silk-covered copper wire (12 or 14 B.W.G.) which has been run through melted paraffin wax before winding. The layers are separated by paraffined paper.

Let us, for the moment, ignore the secondary coil, and consider exactly what takes place in the primary as the current is made and broken.

On making, a current rushes through each loop of the primary wire, inducing momentary opposite currents in the next loop of the primary wire on either side of it. This will oppose, and, therefore, retard the original current; but, as it is only induced momentarily, it does not stop the battery current, but merely causes it to gradually reach its maximum. This effect is known as *self-induction.*

On breaking, a self-induced current tends to pass along in the direction originally taken by the battery current. This being of high electro-motive force, is apt to spark across the contact breaker, thus causing the break to take place slowly, or not at all. To avoid this, the condenser is introduced, as already explained. It acts as an electrical cushion, absorbing the shock of the self-induced current, and giving it back again to slacken the strength of the make in the primary. The total effect, then, is that *the make is gradual*, whilst *the break is sudden.* By removing the condenser from a coil working with a mechanical contact breaker, the suddenness of the break is so altered that the resulting spark from the secondary coil is reduced quite 90 per cent. in length, whilst the spark at the contact breaker is greatly increased. The primary coil, with its core, is usually covered in with a tight-fitting case of thin ebonite, which insulates it from the secondary.

The Secondary Coil.—The wire of this coil is very fine (36 B.W.G.), as it has only a small current to carry. But, on account of its high electro-motive force, the wires must be insulated with the greatest possible care. With small coils this is done in many ways, sometimes making the whole coil into a solid mass by filling up the gaps between the wires with melted resin. The insulating material used nowadays is usually some form of paraffin wax.[1] For small coils silk-covered wire is run through melted wax and wound evenly on the bobbin. Where a layer is *in situ* it is painted with hot wax so as to leave no air spaces, and waxed paper carefully wrapped round it whilst still warm, again avoiding any imprisonment of air. The winding is thus continued, putting on layer after layer, insulating one loop from the next by wax, and one layer from another by waxed paper.

In large coils the secondary is wound in sections. The bobbin is divided up by insulating discs of ebonite, waxed paper or mica. In the sections so formed are wound a series of disc-shaped coils insulated by means of wax.

The advantage of this system, introduced by Messrs. Siemens & Halske, is very great. Since the potential of the wire rises fairly regularly from one end to the other, it follows that the first loop on a coil wound in the old way is at a very different potential from the one lying nearest to it on the second layer, as there is a great length of wire between the two. Hence the insulation in such places is liable to give way.

In the sectional coil, no loop is very different in potential from those lying nearest to it, the maximum difference being

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[1] Mr. W. H. Cox tells me that he uses a mixture of paraffin wax, ozokerite and resin, which will not melt at any temperature to which the coil is likely to be exposed.

between the ends of the coil and not between the inner and outer layers.

The terminals of the coil are connected with discharging rods usually fixed on pillars standing on the base-board of the coil.

A word or two should be said here about the quality of wax used in making a coil. Workers in temperate climates seldom have trouble with the wax of their coils. On page 196 mention is made of a case where the wax melted out of a coil during a long railway journey. A case of another kind has been described to me by my brother, Mr. J. E. Addyman, of Colombo. In the intensely damp and hot climate of this town his advice as an electrical engineer was asked with regard to a large coil which continually went wrong. He found that the insulating material was absorbing moisture and thus losing its dielectric qualities. The defect was remedied by making a special case for the instrument which contained a zinc drawer covered with a perforated zinc top and containing quicklime. After standing for some time in the artificially dry atmosphere so caused, the paraffin recovered its insulating powers, and the coil began to work as before.

Another case brought to my notice some years ago (before Roentgen's discovery), of a small coil breaking down, was traced to the rotting of part of the secondary coil. In this case the paraffin was found to be impure and to contain stearic acid.

Paraffin wax of various melting-points is readily obtainable, the usual grades being from 105° to 135° F., and it may be readily tested for fatty acids by melting and adding a crystal of rosaniline. Paraffin, if pure, is not coloured by the dye. Any good coil maker will make a coil specially for hot or damp climates if asked to do so.

Contact Breakers.—Many inventors have turned their attention to the improvement of contact breakers. The result is an enormous number of devices. There are far too many to be described in detail here, but each works on one of three or four well-defined lines, so that a description of a few types will enable the worker to readily understand any one which is likely to come into his hands.

From what has been said (see page 62) concerning the working of the primary coil and its core, it will be seen that the "making" of the current takes an appreciable time. Therefore it is advantageous to have some means of regulating the rate at which the contact breaker works, and also if possible some means of regulating the ratio between the time during which the current passes, and that during which there is no current.

The importance of this last point will be best appreciated by a consideration of the difference between the effects of the make and the break. When the current is started (make) it takes an appreciable time to reach its maximum, so that to obtain the full effect of the break it should be allowed to flow until the self-induction is overcome and the highest possible current is passing through the primary. With the break it is different. As soon as the break has taken place (and the more instantaneous it is the greater the inductive effect) the coil is ready to have the current made again. Thus, to get the highest inductive effect, the period during which the current is passing should be as long as possible, and the period during which none is passing as short as possible, or in other words, for all periods of vibration, the higher the ratio of the make period to the break period and the more efficiently will the coil work.

Breaks may be conveniently divided into four classes: automatic breaks, separate magnetic breaks, mercury breaks and electrolytic breaks.

Automatic Breaks:—

(*a*) *The Apps' Interrupter.*—Mr. Alfred Apps, who has devoted a great many years to the study of the induction coil, and who has made some of the finest coils in the world, patented, in 1867, a simple but very effective break. It is shown in Fig. 21, and is the same in principle as the one in Fig. 20. The improvements are twofold. Firstly, the tension screw, T, when turned to the left, strains the spring, S, towards the standard, A, thus causing the contacts, C E, to press more strongly together. The greater this pressure and the slower will be the rate of vibration, thus allowing of a more complete magnetisation and demagnetisation of the core. At the same time it lengthens the time of contact between the platinum piece to a greater extent than the time of non-contact. The second improvement is in the material of which the spring is made. Changes of temperature alter the elasticity of a metal spring very greatly, and continuous working of a large coil often makes the break very hot. Moreover, it will not stand the continuous alteration in the strain caused by the tension screw. Apps' brass is wonderfully durable, and although it is not perfect in retaining its elasticity as the temperature rises, it is certainly better than any other metal at present in use.

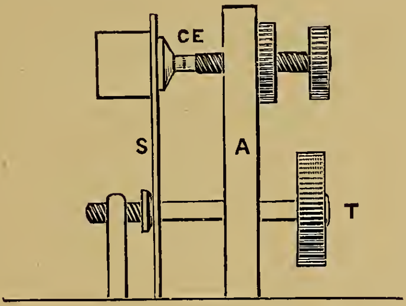

FIG. 21.—Apps' Interrupter.

The great advantage of the Apps' interrupter is that it is regulated entirely by means of one tension screw. A 10-in coil (nominal) may easily be made to give any length of spark from $\frac{1}{4}$-in. up to 12 ins., by simply turning this single screw.

Its drawback is that the pressure between the contacts, if too great, is not easily overcome, and this tends to render the break not quite so sharp. The question of the most efficient pressure has been investigated, I believe, by Mr. Bowron, whose break is described below.

The Apps' break has many imitations, which are usually much cheaper. Should circumstances necessitate the buying of such an one, care should be taken that the platinums are smooth and wide, and that the tension screw works easily and evenly.

The practical details of working with this break are very few. Attention should be paid to the condition of the platinum contacts. These should be kept perfectly flat by filing down any roughness, and then polishing with emery paper. During work one of the contacts will become more or less pitted, and the other will become roughened by the projection of particles of platinum across the intervening space during the "break". When starting work with carefully *flattened contacts*,[1] the spring should be set absolutely free by releasing the tension, and

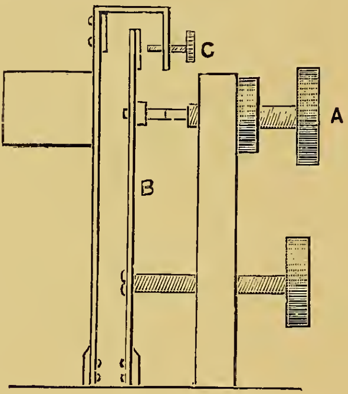

Fig. 22.—The "Vril" Break.

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[1] This cannot be too strongly insisted upon. A coil which, with contact well flattened and polished, will give a 12-in. spark, will often only work up to 9 ins. with rough contacts.

the top screw adjusted so that interval between C E is very small. For the utmost effect of the coil this interval may be as much as $\frac{1}{16}$-in., for smaller effects less; but it is always as well to have a slight space so that the current does not start until a slight tension is applied.

(*b*) *The Vril Break.*—This device is, like the Apps' break, a type from which several others are variations. It will be understood on reference to Fig. 22. It consists of a standard of brass which supports a tension screw and contact screw as before. But instead of the single spring holding both contact and weight, two springs are used, one for each. The current, before reaching the primary coil, has to pass up the standard, through the contacts and down the contact spring, B. When the current passes, the magnetism of the core attracts the weight. This bends the weight spring, but does not instantly break the circuit, for it has to travel through a certain distance before the tip of the screw, C, catches the head of the contact spring, and thus separates the contact. On the other hand, the "make" occurs before the weight has completed its backward swing. The total effect is, that the ratio between the times of current and no current is widened out, and the current in the primary is enabled to overcome the various retarding effects and reach its maximum before the break occurs.

All mechanical breaks are noisy, but the extra noise which would be expected from the double spring arrangement may be overcome by placing a thin strip of rubber on the top of the contact spring, where it strikes the screw, C. I have seen a Vril break working with a rubber cap over this screw in addition to the strip on the contact spring.

This break, when once started, is entirely regulated by the tension screw; but the preliminary setting is rather more complicated than in simpler breaks. The screw, A, must be set —with the tension slack—so that the contacts are almost touching. The screw, C, will also need setting.

It will be noticed, as an advantage, that this break gives a prolonged "make" without placing a large tension on the spring. This has the effect of saving the platinum, which does not wear away as rapidly as in the simpler forms.

(*c*) *The Bowron Breaks.*—Mr. G. Bowron has paid considerable attention to the manufacture of efficient breaks, and has made careful measurements of the efficiency of various forms. At the January (1900) meeting of the Roentgen Society, he showed improved forms of mechanical breaks in which he removed the strain as much as possible from the springs. His experience leads him to believe that the pressure of the contacts just before the break should not exceed the weight of 8 oz., and he even seems to think that a reduction to 4 oz. would have a good effect.

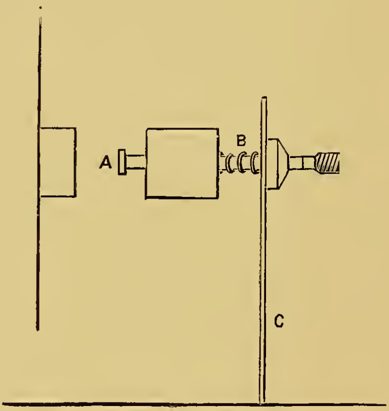

FIG. 23.—Bowron Break.

The first break is adapted for coils giving up to 6-inch spark. It is similar in general appearance to the Apps' form, the only part needing description being the weight. This, instead of being rigidly connected with the spring, slides along a rod, A (Fig. 23). When the current passes, the weight moves along the rod, and in doing so extends the spiral spring, B.

When the tension on this spring rises sufficiently to overcome the tension on the contact spring, the contacts are separated. At the break the weight flies back under the action of the spiral. This has the same effect as the Vril in prolonging the time of contact, thus giving a spark of given length with less expenditure of primary current.

It may be objected that a longer contact must naturally use more current, but the reasonableness of the above statement is at once seen when put the other way round. Without increasing the current we obtain a longer and thicker spark.

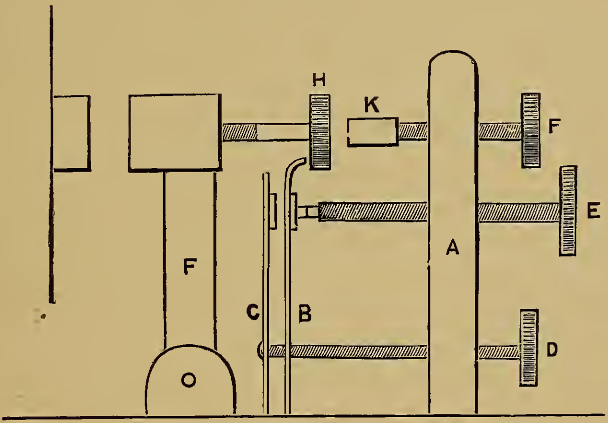

Fig. 24.—The Bowron Break.

The second form, used for larger coils, and capable of taking a very powerful primary current, is much more complicated. It is shown diagrammatically in Fig. 24. A is a brass standard, which supports three adjustable screws. B is a contact spring, which presses the platinum contacts together with just the requisite force. C is a separate tension spring, which may be adjusted by means of the screw, D. Near the head of this spring, C, is a rubber buffer, which regulates the extent of free movement of the contact spring. F is a bar of soft iron, surrounded by a coil of copper wire, so that it may be magnetised if necessary. At its upper end it carries the usual iron weight, but at its lower end it is hinged so that it may swing freely. As it swings forward towards the core its movement is checked by the contact spring, B, which catches the screw-head, H, made of ebonite. After breaking the contact, the two springs, B and C, come together and oppose the forward movement with their combined resistance, which is increased, if necessary, by applying tension with the screw, D. As the weight swings back on its hinge, its ebonite screw, after freeing the springs, is checked by the india-rubber buffer, K, whose position is regulated by the screw, F.

The great advantage of this break is that the pressure at the point of contact is always the same, since the tension spring acts only on the swinging of the hammer, and not on the platinum contacts. High-pressure currents (25 volts for a 10-in. coil) may be used with this break, but it is advisable to connect the coil surrounding the hammer, in series with the primary when using such currents. It appears to be highly efficient, and is much cleaner and more amenable to transport than the mercury breaks to be described later.

Separate Mechanical Breaks.—Some makers, as the Volt-ohm Company, make coils without interrupters, and all first-class makers have special sets of terminals on their coils which allow of the use of some external means of making and breaking. Usually a mercury break or electrolytic interrupter is selected for use externally, but some workers prefer one of the so-called electro-magnetic breaks. These are usually something between the Apps and Vril in construction, with the addition of an electro magnet, which acts on the hammer in the same way as the primary of the induction coil.

Mercury Breaks.—In this class of apparatus contact is made by dipping a conducting wire into mercury. This is, naturally, more efficient than bringing together two pieces of platinum, as the contact between the wire and the mercury is so much more perfect. On the other hand, vessels of mercury are not readily moved from place to place without a certain amount of messiness.

Foucault's interrupter, which is the simplest form, consists of an iron weight on a spring which is attracted to the core of the primary at each make, bearing a long copper wire so arranged that its end just dips into a vessel of mercury at the backward swing, and moves up free of the mercury at the forward swing.

In this form it is scarcely ever used for X ray work, as, although efficient for small coils, it works too slowly for use with a screen, and churns up the mercury rather badly. If a clean surface of mercury be used, it is rapidly oxidised. If the surface is covered with paraffin oil or water, the mercury soon breaks up into very fine globules, which makes the insulating liquid a conductor. Hence it is useless for prolonged exposure.

This breaking up of the mercury is the great drawback to all mercury breaks. It is partially overcome by setting the wire exactly at right angles to the surface of the mercury, and arranging the apparatus so that it strikes up and down without any alteration in the direction of its longer axis.

This cannot be managed with a swinging arrangement, hence the better class of mercury break is worked either by a small electro-motor or by clockwork. Even an accurately dipping break causes some churning, but this may be reduced to a minimum by altering the viscosity of the mercury. This should be increased until it is as different as possible from that of the supernatant liquid, whether petroleum or water.

When two unmixable liquids of similar viscosity are shaken together, they tend to form a more or less permanent emulsion, whilst two with very different viscosities have no such tendency. This may be readily shown by shaking up two stoppered bottles, each containing a little mercury, covered in one case by strong sulphuric acid, and in the other by water. On allowing them to settle, the mercury takes much longer to assume its permanent form in the acid bottle that in the water. In practice the viscosity of mercury is generally increased by dissolving platinum in it to form a liquid amalgam. The proportions usually recommended being 7 parts of mercury to 1 of platinum.

Probably the best of these dipping mercury breaks is the one invented by Max Kohl. The motor is worked by a separate battery, and the speed is regulated by either a break or a rheostat. For accurate work a speed indicator is attached, so that conditions which may have been successful at one time can be exactly reproduced. Here the ratio between the times of current and no current are regulated by a lever, which raises or lowers the mercury vessel. When the level of the mercury rises, the dipping wire is immersed during a longer portion of its voyage, giving a longer period when the current is made. Since the distance through which the wire travels is constant, the period during which the current is broken decreases, as the period of "make" increases.

A great advantage of this break, which is only fully realised after a little experience in its working, is that it may be started and adjusted to the required conditions before any current is sent through the coil.

Its disadvantages are the uncleanliness already referred to, and the necessity for accurate levelling before starting work. This last is of course no drawback when the installation is a stationary one, but when apparatus must be carried from place to place it is very trying. Dr. Mackenzie Davidson has recently introduced a form of mercury break in which the contact is made by a knife rotating on a nearly horizontal axle. It is so arranged that at each revolution the edge of the knife slides through the surface of the mercury.

Mercury Jet Break.—Another mercury interrupter working on an entirely different principle is shown in Fig. 25. It is rather complicated in construction, but its method of working is readily understood. An upright spindle worked by a small electro-motor rotates in a vessel whose lower part is filled with mercury. As the spindle rotates it carries round a series of sheets of copper, which are to be seen inside the glass vessel, and are shown separately in Fig. 26. At the same time it works a pump. This directs a jet of the mercury outwards from the centre of the vessel in such a manner that, as the copper plates pass round, the jet strikes them one after another. The current is conducted along the jet of mercury, which makes contact with the copper plates, and of course breaks the current in the spaces between the plates. To prevent any sparking, the vessel is nearly filled with paraffin.

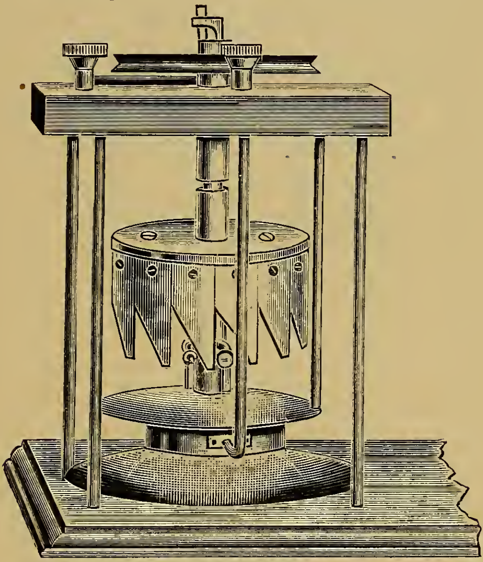

Fig. 25.—Mercury Jet Break.

The rapidity of make and break is governed by the rate at which the spindle is revolved, whilst the ratio between the time of current and the time of no current is regulated by the ratio between the sizes of the plates and the intervals between them.

Electrolytic Breaks.—Wehnelt found that the rapid and regular alterations in the strength of a current electrolysing dilute acid can be arranged so as to make a very efficient form of contact breaker. By using electrodes of enormously different sizes, as, for instance, the point of a platinum needle for the negative and a large sheet of lead for the positive, the current is made and broken at a high speed and very perfectly. Indeed the break is so sudden and perfect that it does away with the necessity for a condenser, and already in the catalogues of certain makers we find quotations for coils without condensers.

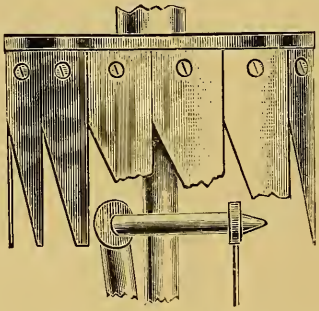

Fig. 26.—Working Parts of Mercury Jet Break.

The Wehnelt break is manufactured in many forms of more or less complexity. The simplest form may be readily put together by any one who wishes to make experiments with it. A piece of glass tubing, No. 4 size ($\frac{1}{4}$ in. internal diameter), 8 in. long, is drawn out at one end in a gas flame, and a piece of thin platinum wire $\frac{3}{4}$ in. long is fused into it so that between $\frac{1}{8}$ in. and $\frac{1}{4}$ in. projects from the end, the rest being inside the tube. This will form the negative point. The tube is fitted into a piece of wood (A, Fig. 27), which may be placed across the top of a jam pot. A little mercury, B, is poured into the tube, and a copper wire connected with the negative pole of the battery or other source of electricity. A piece of sheet lead is bent so as to form a lining to the sides of the pot, and connected by a copper wire with the negative terminal of the primary coil. The positive terminal of the primary is connected with the positive pole of the battery. The jam pot is partly filled with dilute sulphuric acid (sp. gr. 1·205), and the break is complete. When the current is turned on, the break works with a humming sound.

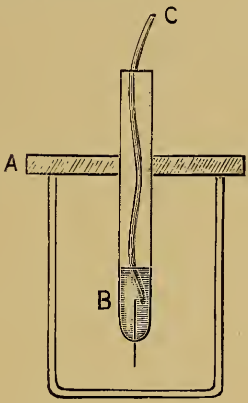

Fig. 27.—Section through portion of Improvised Wehnelt Break.

The various forms of this break have platinum points which may be regulated as to size and position by mechanical means; and in some cases attachments for cooling the acid and for getting rid of the gas which is formed by decomposition of the electrolyte.

Although a battery giving 12 volts pressure will work this break when its resistance is sufficiently small, it is usually stated that the voltage necessary is from 50 to 100 volts. The makers supply it specially designed to work with whatever electro-motive force the operator may have at his disposal. As very many direct systems are now worked at

200 volts, it is advisable in such cases to use a rheostat with the break, though high-resistance breaks can be supplied for use with this high pressure.

The effect of this break is to give a torrent of sparks at the terminals of the secondary coil which partakes of the nature of a flame, but the spark-length is slightly shorter than with a mechanical break. When this secondary current is passed into an ordinary focus tube, it will very soon destroy the anode by melting a hole in the platinum. When the rheostat is used so as to decrease the current going through the break, and thus to insure the safety of the tube, a very brilliant and steady illumination of the fluorescent screen is obtained. The drawbacks to the use of this break are various. Besides the liability to spoil your tube, it is rather messy and ill-adapted for moving about. Moreover, the platinum point soon wears out, and its renewal is not easy to an amateur instrument maker.

In the chapter on "Tubes" will be found a description of several special forms of focus tubes designed for use with the Wehnelt break. As these are very expensive, they constitute a further drawback to its use. In fact this break, although undoubtedly capable of very good work, especially with the fluorescent screen, is very little used for X ray work, and most experimenters, after using it for a while, discard it for one of the older forms.

The Commutator or Current Reverser.—Every good coil is supplied with this little attachment, which enables the operator to send the current in either direction through the primary, or to stop the current at will. An end view is shown in Fig. 28 (I.) and a longitudinal section in Fig. 28 (II.). A cylinder, A, of some non-conducting material—usually ebonite—has two strips of copper, D D, fixed longitudinally on its surface. This is supported horizontally between two metallic uprights, + B – B, which are connected with the two terminals of the battery. Each of these uprights has a metallic connection, the details of which are shown in II., with one of the copper strips. The ends of the primary coil are connected with springs, + C – C, which press against the sides of the cylinder. As one of the strips is now in direct connection with the positive pole and the other with the negative pole of the battery, when the handle is in the position shown in the figure + C is in connection with + B. By turning the cylinder, A, through half a revolution, + B is brought into contact with – C, and the current through the primary thus reversed. When it is rotated through a quarter of a revolution from the position in the figure, the springs do not touch the strips, so that the current is completely stopped.

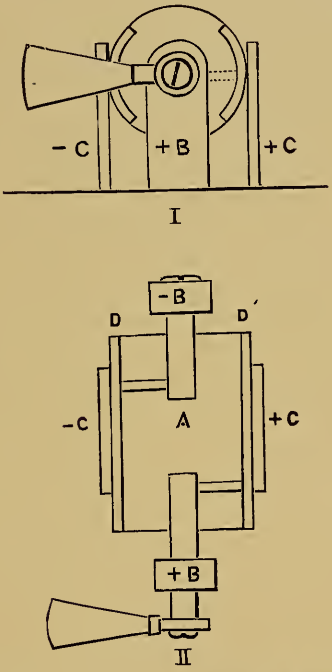

Fig. 28, I. and II.—Current Reverser.

Terminals on a Coil.—Most large coils are made with terminals, or binding screws, so arranged that an outside break may be used if necessary. In the Apps' or Apps-Newton coils the arrangement is shown in the diagram, Fig. 29. Nos. 1 and 2, which are usually marked P and N, are for connection with the battery under ordinary circumstances when working with the automatic break. Nos. 3 and 5 are the terminals of the condenser, and are connected in ordinary work by short wires with 4 and 6 respectively. Nos. 4 and 6 are terminals of the primary without the contact breaker, but including the commutator. Nos. 7 and 8 are connected directly with the primary coil, and have no connection with commutator, break or condenser. By removing the connections between 2 and 4, and 3 and 6, the condenser is put out of action.

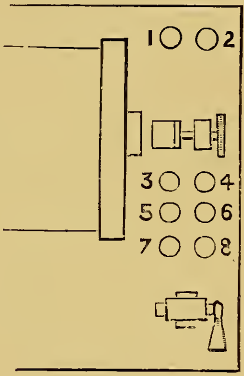

FIG. 29.—Connections used in an Apps' Coil.

To use a mercury or other external break, the connections just mentioned are removed, and the wires carrying the interrupted current from the break are threaded one through 4 and 3 and the other through 6 and 5. The commutator will still be in action, but not the mechanical break.

Nos. 7 and 8 are used when the coil is employed as an ozoniser. A powerful alternating current may be sent through the primary from these terminals. The only fear of damage to the coil from this heavy current is that it may overheat the primary. To guard against this the Apps' coils have an opening at one end leading into the core of the primary coil. When using it as an ozoniser, a thermometer may be fixed in this opening.

CHAPTER IV.

ELECTRO-STATIC MACHINES.

An electro-static machine is not only a source of power, but since the discharge which it produces is one of very great potential difference, it may be considered as equivalent to a source of power and transformer in one. By its use we dispense with both coil and battery. Hence, instead of describing it in the section dealing with sources of power, it has been thought better to explain its action in a separate chapter.

All the earlier machines produced statical charges by means of friction, but the ones used for production of X rays are the more modern instruments which work by induction. Mr. Wimshurst's machine and its modifications act in this manner, producing large statical charges of such high voltage that they give results exactly similar to those of an induction coil. In fact, by overcoming the resistance of the air or the vacuum of a Crookes' tube, they become highly dynamic.

Wimshurst's Machine.—The simplest form of this machine is shown in Fig. 30. It consists of two circular plates of glass close together, mounted so that they may be rotated in opposite directions. In the figure only one of these can be seen, as it hides the other one completely, or nearly so. Fixed in a ring to the outer sides of the glass plates are a series of metallic strips which act as travelling conductors, whilst the glass plates which separate one series from the other act as dielectrics. Here again the figure only shows one set, the other set being on the distant side of the hidden plate.

The brass rod, which is shown as running across the face of the glass disc from the top left-hand to the bottom right-hand part, carries at each end a wire brush which makes contact with the face of each travelling conductor as it passes.

A similar rod is shown by dotted lines on the far side of the hidden plate, but running across at right angles to the first rod.

This completes the generating part of the machine, the remaining parts being apparatus for collecting the successive small charges which are induced in the conducting strips.

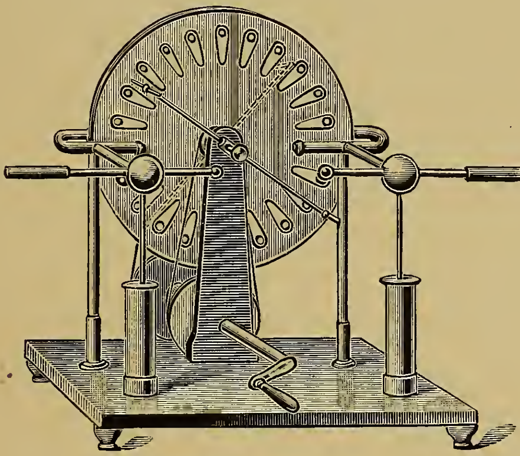

Fig. 30.—Simple Form of Wimshurst Machine.

When the machine is set in motion, the plate seen in the figure will travel in the direction of the hands of a watch. Consider the topmost strip, which we shall suppose to possess a small positive "*initial charge*". After moving round to the right through an eighth of a revolution, it arrives opposite a strip in contact with the brass rod marked by a dotted line in the figure. This strip, being on the back plate and travelling in the opposite direction, is, of course, only in this position momentarily, but during that moment it has been subject to induction, and at the same time connected with another strip diametrically opposite to it. It therefore travels on with a negative charge, whilst that with which it has been momentarily connected moves on with a positive charge.

Continuing round to the right, the positive strip arrives opposite the prime conductor, to which it gives up its charge. It passes through another eighth of a revolution chargeless, and then coming into contact with the "earthing" brush, and at the same time finding itself opposite a positively charged strip on the other plate, it receives a negative charge. This charge it carries round to the other prime conductor, but on its way performs its inductive work, producing a positive charge on a strip on the other plate.

Thus the strips on each plate bear a constant stream of negative charges to the left-hand conductor, and a corresponding stream of positive charges to the other, producing a high difference of potential between the two discharge nobs, shown at the front of the apparatus. This difference is manifested by a stream of sparks between the nobs.

Initial Charge.—The foregoing description hypothesises an initial charge on one or more of the strips. After the machine has been once used and then left at rest, the strips on one part of a plate will be left at a very different potential from those on another part. A current will leak across through moist air or over the surface of a damp plate, gradually reducing this difference, but since this leakage will become more and more sluggish as the difference lessens, it will eventually almost cease, and some little difference will be left.

The smallness of the charge scarcely matters, as induction machines of this class work at what has been called compound interest. During the first few revolutions the potential difference rapidly increases until the full efficiency is reached, so that a very small initial charge only means that the machine will take a rather longer time before giving its full power. Hence the Wimshurst machine is said to be "*self-exciting*".

Leakage.—The leaking of the charges across the plates, which has just been referred to, is always taking place whilst the machine is working. Glass is very hygroscopic, and therefore is apt to form a conducting surface of moisture. Ebonite plates have therefore been used. This substitution should make the whole apparatus much less fragile, and more portable. Unfortunately, ebonite plates have a habit of warping. A better method is to cover the glass with a waterproof varnish, which is less apt to condense moisture. As a further precaution, larger machines are usually enclosed in glass cases, the interiors of which are kept dry by means of some desiccating substance, such as calcium chloride or lime.

Another source of leakage to which these machines are peculiarly liable is to be found in any roughness or points on the prime conductors. A machine, which readily gives sparks several inches long from nob to nob, may be rendered comparatively useless by wrapping a few turns of fine wire round one of the conductors and leaving the ends exposed.

Multiple Machines.—The electrical effect obtained from such a machine as has just been described is an enormously high difference of potential between the discharge nobs, but the current which passes in the spark is very small. This defect is overcome by connecting a set of machines in parallel, so that, although that they do not increase the potential difference, they greatly increase the quantity of the discharge. When several pairs of plates are arranged in parallel, they form a multiple machine, a machine with four pairs of plates, each having a diameter of 18 ins., costs about £20, and gives a 7-in. spark. This will excite an X ray tube sufficiently to give good screen effects. Unfortunately, it is both heavy and fragile, so that it cannot be considered portable. Still, for stationary work it is excellent, being clean and always ready for starting.

The Holtz Machine.—This is a machine which resembles the Wimshurst in that it depends for its action on electro-static induction, but is very different in its constructional details.

The simple form of the machine is shown diagrammatically in Fig. 31, in which the same letters are used for corresponding parts. One of its plates is stationary whilst the other revolves. A, the revolving plate, is a plain disc of glass; B, the stationary plate, is a square or circular piece of glass in which two holes,

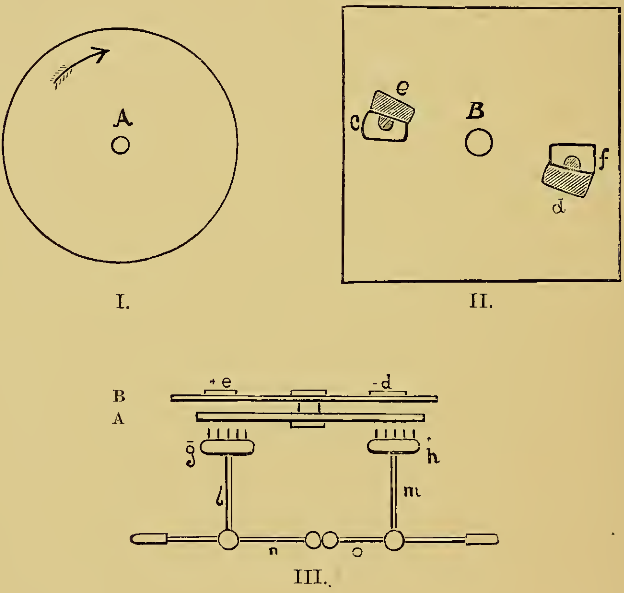

Fig. 31.—Holtz Machine.

c and *d*, are cut close to these holes, and on the side of the plate remote from the revolving disc are fixed two paper armatures, *e* and *f*. These strips of paper have projecting tongues which point through the holes or windows and reach very nearly to the movable disc. The tongues point in the opposite direction from that in which the plate A moves. On the other side of the moving plate (*see* Fig. 31, iii.) are arranged two brass collectors *g* and *h* (rods of brass with sharp projecting pins pointing towards the glass). Each of these points directly towards one of the armatures.

Connection is made between the two collectors or combs by the brass rods *l* and *m*, and the sliding dischargers *n*, *o*.

To work such a machine the two dischargers *n* and *o* must be brought together so that the nobs at their ends are in contact, a small charge must be given to one of the armatures *a* or *b* by means of an electrophorus, and the plate A must be turned quickly. After a few turns the discharge rods may be separated, when a torrent of bright sparks will flash across between the nobs.

To understand the working of the machine, we must remember that a charge may reside on the surface of a plate of glass. Supposing that the armature *a* has a positive charge, this acting across the glass plates will attract a negative charge to the points of the comb *g*, and repel a positive charge to the points on the comb *h*.

Negatively electrified air will stream off the points of the comb *g* on to the glass. It will be carried round until it comes opposite to *h* where it will be neutralised by the positive charge flowing from *h*, at the same time inducing a further positive charge in *h*, and a stronger negative charge at *g*.

As the plate continues revolving, the positively electrified wind from *h* will give a positive charge to the lower half of the surface of the plate.

Further, the larger positive charge of *h* will induce a negative charge in the armature *f*, repelling a positive charge to its farthest point, *viz.*, the tongue. A positive electric wind will therefore play on the back of the rotating plate from the tip of the tongue, thus causing both sides of the lower half of the plate to be electrified positively, and both sides of the upper half to be electrified negatively.

After working for a few turns, the nobs *n* and *o* may be separated, and the difference of potential between *h* and *g* will be sufficient to maintain a discharge between them.

The chief practical difference between the Holtz and the Wimshurst machines is that the Holtz is not self-exciting, so that it is necessary to start it by applying an electrophorus to one of the armatures.

In America the Holtz machine is much used for X ray work, and very large multiple machines are manufactured, having six or eight pairs of plates, with the movable plates all on one axle. Such a machine is at work in London at St. Bartholomew's Hospital. It is run by an electro-motor. Its collectors are connected to two circuits, one of which leads to the focus tube, and the other to the discharge rods, so that the machine may be started, *i.e.*, the rods may be brought together without disturbing the tube.

Practical Work with Influence Machines.—It will be convenient here to mention the principal differences between X ray work with statical machines and that carried out in the ordinary way with induction coils. The liability to leakage especially from points has already been mentioned. This necessitates special connections.

The discharge rods of an influence machine always terminate in well-rounded and polished nobs. Instead of connecting the wires to these nobs with binding screws, special plugs may be fitted to the wires and run into holes in some part of the conductor, or else the wires are permanently connected so as to leave no loose ends of wire. Mr. Wimshurst uses a special holder for the tube in which the connection between the wire and the outside terminal of the tube is closely surrounded by an india-rubber cap.

More usually one end of the tube is connected with the machine in this way, whilst the other end is free. The free terminal of the machine is connected with a polished brass nob, which is brought up close to the terminal of the tube, but not allowed to touch it, thus interposing a spark gap. It is found that by this method of excitement very considerable control may be exerted over the quality of the rays proceeding from the tube. Lengthening the spark gap naturally increases the resistance of the circuit, and this acts as though the internal resistance of the tube were increased; that is to say, the tube becomes temporarily harder (see p. 93). In the same way, shortening the spark gap gives rays, of smaller penetration, or softens the tube. This phenomenon has not been observed with the current from an induction coil.

In taking radiograms, Dr. Lewis Jones states that longer exposures are required with a statical machine than with induction coils, giving the same length of spark.

Varying the Current from an Influence Machine.—Mr. Wimshurst finds that the current given by his machines varies approximately with the number of revolutions per minute. The reason for this is somewhat peculiar, and has been fully investigated for the Holtz machine, which follows much the same law. In S. P. Thompson's *Elementary Lessons in Electricity*, section 53, occurs the following paragraph:—

"Righi showed that a Holtz machine can yield a continuous current like a voltaic battery, the strength of the current being nearly proportional to the velocity of rotation. It was found that the electro-motive force of a machine was equal to that of 52,000 Daniell's cells, or nearly 53,000 volts, at all speeds. The resistance, when the machine made 120 revolutions per minute, was 2810 million ohms, but only 646 million ohms when making 450 revolutions per minute.

CHAPTER V.

TUBES.

In the historical portion of this book a short summary has been given of Crookes' work on radiant matter, which led up to Roentgen's discovery.

The first type of tube to be used for the production of X rays was that shown in Fig. 3. The terminal, which is connected with the negative end of the secondary coil, technically known as the cathode, consisted of a disc of aluminium, whilst a positive disc or anode of the same metal was placed to one side. When such a tube was excited, the stream of molecules moved along the tube normally to the disc, and kept up a bombardment on the end of the tube. This generated X rays at the surface of the glass.

To obtain a very clear and well-defined shadow, whether by light or any other form of radiation, the first necessity is that the source of illumination shall be as small as possible. It is impossible to get a clean-cut shadow when the source of radiation is as large as the end of a Crookes' tube. Hence the earlier X ray photographs lack definition. The area of glass from which the X rays are generated may be reduced and the definition improved by using a concave cathode, which sends out a converging stream. This, however, soon melts the glass. Nowadays some form of focus tube is always used.

The Focus Tube.—Mr. Herbert Jackson used a concave cathode, but instead of allowing the converging stream of molecules to impinge on the glass, he brought it to a focus on a platinum anode, which was inclined at an angle of 45° with the axis of the molecular stream. This anode, or rather a small spot on its surface, becomes the centre from which X rays are emitted. The glass is blown out as thin as possible, having due regard to strength, and if it be well and evenly made, it gives as good results as any form of tube yet invented.

In selecting a focus tube for practical work, two points must be insisted on: Firstly, that the cathode stream focuses accurately on the platinum anode, and thus generates X rays only from a small circular spot; secondly, that the vacuum is correctly adjusted to suit the coil and kind of work to be done.

Accurate Focus.—On page 6 a description has been given of the different effects which are produced by an electrical discharge through a vessel from which the air is being gradually removed. Whilst pumping the air from a focus tube, an electrical discharge would undergo exactly the same changes, until it arrived at the state where fluorescence begins in the glass. This is easily noticed because of the entirely different colour of the green fluorescence from the purplish glow of the air within.

If the tube has been accurately made, the anode will be placed considerably beyond the centre of curvature of the aluminium cathode. Soon after fluorescence starts in the glass, the track of the cathode stream can be seen marked out as a pale violet glow within the tube. It will be seen to converge to the centre of curvature, then spread out again so as to bombard the whole of the platinum anode. On exhausting further the shape of the stream changes, the convergent cone lengthening out, as though the highly electrified particles had a repelling action on one another, and were therefore slower in coming to a focus. At a still higher state of exhaustion the cone elongates still more, and instead of the stream diverging after coming to a focus, it simply moves onward in a very fine thread, which strikes the anode, or anticathode, as it is sometimes called, only on one small spot. As the exhaustion has proceeded, and as this blue cone has become more and more elongated, it has become fainter until, a little later, it is quite invisible.

An accurate focalising of the cathode stream on the anode, which starts all the X rays from a single well-rounded spot, is the condition which determines well-defined shadows, and enables us to take sharp radiograms, with many structural details of the bones.[1]

A rough and ready method of testing a tube, which, however, can only be used where the anode is of light structure, is to set the tube working until the anode just begins to glow. If a very tiny, well-rounded red-hot spot forms on the platinum, the tube will probably give good definition. If a large spot of irregular shape, or several spots at once grow red-hot, the tube should be rejected.

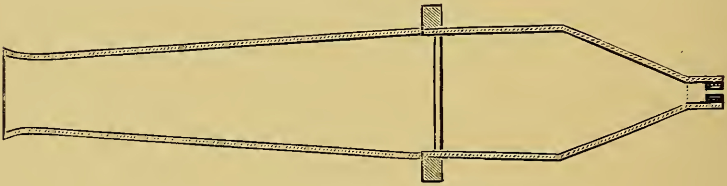

FIG. 32.—Pin-hole Camera.

But since tubes are a heavy item in the expenditure of the X ray worker, it is as well to have some accurate means of testing the size and shape of the point of emission.

An ingenious little instrument has been devised by Mr. Campbell Swinton for either photographing or making a fluorescent image of this radiant spot. It is shown in Fig. 32. A

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[1] Of course there are other conditions which must be fulfilled if we wish to obtain a sharp radiogram. These are explained in a later chapter. The statement here given simply relates to the condition which must be fulfilled by the focus tube.

leaden tube is so shaped that at one end, the right-hand side of the figure, it is pierced only by a pin-hole. Some little distance behind this hole is placed a fluorescent screen, whose prepared surface faces the open end of the tube. The well-known optical phenomenon of a pin-hole image is formed on the screen, and may be perceived by looking in at the open end. This image will be a representation of the source of radiation, and should be round, small and sharply defined.

The Vacuum and Its Influence.—Lenard noticed that the cathode rays which he had discovered outside the tube, were affected by a magnet, though not to the same extent as the cathode rays within the tube. The X rays, so far as we know, are uninfluenced by a magnet, thus being somewhat sharply distinguished from Lenard's rays. But the X rays themselves are by no means homogeneous, at any rate if judged by their effects. Those emitted by a tube only exhausted to the point when it begins to give out rays, have very little penetrating power. If such a tube be used in making a screen examination of a hand, probably the bones will not be seen, but merely a black shadow of the hand. A very highly exhausted tube will give out rays of such great penetration that they will pass through the bone with almost the same facility as through flesh, giving a very "flat" picture on the screen, in which the bones are scarcely distinguishable from the flesh.

Between these two extremes we can obtain tubes of all gradations. The lightly exhausted tubes are known as *low* or *soft* tubes, whilst those of great penetrating power are known as *high* or *hard*.

Generally speaking, the hardness of a tube may be gauged by its electrical resistance, or the length of spark required to excite it, a low tube requiring a shorter spark than a high one. But there are other conditions besides the vacuum which influence the resistance, such as the distance between cathode and anti-cathode; hence the simplest way to test a tube for hardness is by the use of a screen. A selection of tubes should always be kept by the radiographer. The question of the kind which should be chosen for any special work is discussed in Chapter III., Part III.

Alteration of Vacuum in a Tube.—After using a focus tube for a number of operations, more and more difficulty is found in passing the current through it, and at the same time the rays emitted alter in character, gaining in penetrative power to such an extent that a hand throws but a faint image on a fluorescent screen, and bones become scarcely distinguishable from flesh; in fact, the tube has become hard.

Amongst Crookes' earlier experiments was one showing the difference in the behaviour of different metals when used as the cathode in a radiant-matter tube. Gold and platinum cathodes gradually volatilised in some way, particles of the metal being torn off and travelling with the molecular stream of air. In this way a film of metal was deposited on the glass of the tube. On the other hand, aluminium apparently undergoes no such alteration. Hence, the cathodes of focus tubes are always made of this last-named metal.

If a focus tube which has been used many times be examined, it will generally be found that the glass has a bluish tint wherever the tube fluoresces when in use. This is due to particles of platinum torn from the anode and deposited on the glass. But since finely divided platinum is known to occlude or absorb the gases of air, it is to be expected that the presence of this fine deposit on the glass will tend to increase the vacuum. At the same time the platinised glass will be more opaque to the X rays.[1]

The designers of X ray tubes all take the Jackson focus

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[1] Although the explanation given above is the one usually accepted, there are various objections to it. Mr. Ernest Payne recently noticed that one of the glass supports, which he has been in the habit of using as a holder for his tubes (see page 127), became discoloured in exactly the same way as an old

tube as their type, but add variations with the object either of lessening this alteration of vacuum or of remedying it.

To render the vacuum more permanent and less liable to alteration, various methods have been used. The most obvious is to increase the size of the tube so that the removal of small quantities of air will not appreciably alter the pressure. Another method is to add a subsidiary anode, which enables the tube to take a larger current without injury.

Such a tube is shown in Fig. 33. The glass is blown into a mould, and is thicker than that of the original Jackson tube. This is, however, a very slight drawback. A well-made tube of this type is very strong, and will last a long time. Wherever X ray apparatus is in constant use, as in the London hospitals, these tubes are the ones most generally employed. Their average life is somewhere about three months. Many radiographers consider that the life of a tube is considerably lengthened by using it for some time on a comparatively weak coil (6-in. spark), and only using a 10 or 12-in. spark when the tube has got too hard for the shorter one. On the other hand, Dr. Lewis Jones states, that in his experience, tubes harden much more slowly when used with a powerful

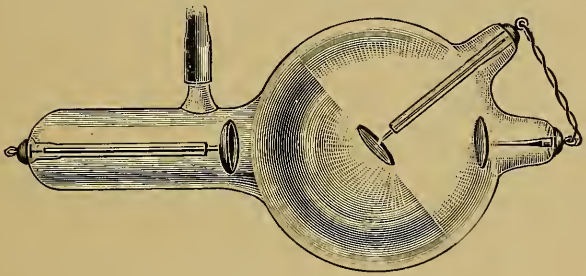

Fig. 33.—Focus Tube (Bianodic).

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tube. It is hardly conceivable that the particles of platinum can have penetrated the tube and reached the piece of glass some inches outside. No adequate explanation of this phenomenon has, as yet, been given.

coil than with a weak one. However this may be, the ordinary bianodic tube will be found to keep its vacuum longer than a similar tube with a single anode.

A modern tube, whose vacuum is very permanent, is the Volt-ohm double-bulb tube, shown in Fig. 34. During exhaustion the larger bulb has been heated, but not the smaller one. This makes a peculiar difference.

Single bulb tubes are always heated, because the inner surface of the glass has a condensing action on the air, preventing its thorough removal by the pump. The application of heat overcomes this condensation. In the double-bulb tube the subsidiary bulb, besides giving an increased volume to the whole tube, acts, to a certain extent, as a reservoir.

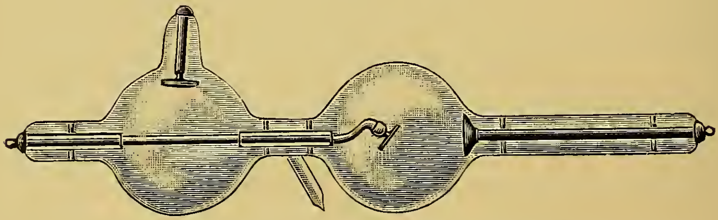

FIG. 34.—Double-bulb Focus Tube (Bianodic).

A further advantage of tubes with double anodes is that their vacuum can, to some extent, be regenerated by reversing the current. If the current be reversed through a Jackson tube, the diagonal platinum plate becomes a cathode, and the conditions are reproduced of Crookes' volatilisation experiment mentioned above. Platinum is rapidly volatilised, and the tube is soon spoiled.

To regenerate a tube whose vacuum has become too high, the two anodes are disconnected, and the *aluminium* anode connected with the negative end of the induction coil, whilst the cup-shaped cathode is now connected with the positive end. After passing the spark for some time in this way, the resistance of a tube is considerably lowered.

The Action of Heat on Tubes.—The earliest workers with focus tubes found that the rays emitted from a tube varied in quality according to its temperature; but the difficulties in the way of making accurate measurements of what goes on either inside or outside a tube under varying conditions are so great that hitherto very little quantitative work has been done in this direction.

Mr. T. C. Porter, of Eton, has carried out experiments on the effects of heat and cold, and found that the tube which he was using refused to work when cooled down by solid carbon dioxide. On allowing it to slowly warm, and examining a hand by means of the rays emitted, he obtained a maximum illumination of the screen at 12° C. (54° F.). At higher temperatures the illumination fell off, and the bones became less distinct.

To show that the radiation at higher temperatures changed in quality rather than quantity, he made two photographs on the one plate, exposing half the plate with a hand over it for one minute, keeping the tube at 15° C. (59° F.). The other half was exposed in the same way for six and a half minutes, after being heated for three-quarters of a minute with a good spirit lamp, and taking precaution that the tube should not cool during exposure. On developing the plate, it was found that "whilst the far denser background of the last exposed half of the plate showed that it had received by far the greater amount of radiant energy from the heated tube during its six and a half minutes' exposure, only the very faintest traces of the bone shadow could be made out in the very bold shadow of the fingers, whilst on the other half, which had received but one minute's exposure to the cold tube, images of the bones are very clearly visible".

Thus, as was to be expected, changes in temperature cause much the same alteration as changes in the internal pressure. A hot tube will always be softer than the same tube when cold.

In practical radiography, where a photograph with good contrasts is required, a very hard tube is useless, excepting in very skilful hands, and the question arises whether the best effects can be produced by using a tube which is soft at the ordinary temperature of the air, or to use one which is kept soft by heating. This subject was discussed by Mr. Wilson Noble in a paper read before the Roentgen Society in March, 1898. He considers that "a tube cannot be too highly exhausted" if one has the necessary power for working it. Further, he states that, "if you have two tubes working with a spark gap of say three inches, one of which has been warmed down to this resistance while the other works at it normally, you will get a far better result with the former tube than with the latter, though the vacuum and resistance in each may, I presume, be considered the same". He accounts for this increase of radiation by considering that the heat energy increases the "activity of the molecules".

These facts with regard to the properties of focus tubes are set forth here to help an X ray worker in his selection of tubes.

For the radiographer who possesses a costly and powerful installation, and who has at his command a large stock of tubes, very brilliant results may be accomplished with hard tubes. But for a general medical practitioner, or other person who is not using the apparatus constantly, and who neither cares to face the large outlay of money, nor is able at any moment to replenish his stock of tubes, it will be best to purchase soft tubes, that is to say, tubes which are easily excited by the coil in his possession. Tubes exhausted for a 4-in. or 6-in. spark will be found the most useful. If heavy work be contemplated, such as the exploration of the thicker parts of the body, at least one tube will be required exhausted for an 8- or 10-in. spark.

As a rule, however, the tubes will be found to harden quickly enough, so that any worker in a small way will generally replenish his stock with soft tubes.

Other Circumstances Affecting Resistance.—Although the penetrative character of the rays from a focus tube seems to depend greatly on the state of the vacuum, it would perhaps be more correct to say that it depends on the resistance of the tube. A high-resistance tube may be hard even with a somewhat low vacuum. The chief circumstances affecting resistance have been investigated by many workers. Crookes found that a tube with a highly fluorescent lining had a lower resistance than one which was lined with a non-fluorescent substance. Hence it is to be expected that a tube which has become black with volatilised platinum, which is less fluorescent than the glass, will have a higher resistance than it had when new, and this quite apart from any alteration in the vacuum due to the occlusion of air. But this hardly affects new tubes. The chief factors, with the exception of the vacuum, which determine the resistance of the tube, are the size of the cathode and the distance at which it is placed from the anticathode. The first of these factors has been investigated by Mr. A. A. Campbell Swinton. To compare the action of various cathodes under exactly similar circumstances, he made a tube with four different sized cathodes, any one of which could be used at will. All were made of one radius of curvature ($\frac{3}{4}$ in.), but their diameters were respectively $\frac{1}{2}$ in., $\frac{3}{4}$ in., 1 in. and $1\frac{1}{8}$ in. With this tube he found that the small cathode caused a high resistance, and gave X rays of the penetrative order, whilst the largest one gave a low resistance and a soft tube.

From many experiments in which he used cathodes varying in diameter from $2\frac{1}{2}$ ins. down to $\frac{1}{8}$ in., Mr. Swinton came to the following conclusion:—

"With the full power of a 10-in. induction coil with mercury break, there is no advantage in making the cathodes more than 1·125 in. diameter. For use with a 10-in. coil, they should not be smaller than 0·375 in. diameter, as, if less than that, they are apt to become overheated, and their surface and form destroyed. For use with 6-in. and smaller coils, very small cathodes, even down to 0·125 in. diameter, will work very well, and will not require such high exhaustion as larger ones. Small cathodes should, in proportion, have a less focal length than large ones for the best results. Probably a good average size for ordinary work is about 1·125 in. diameter, with 0·75 in. radius of curvature. It is important for the best work that the surface should be well polished, and of quite even curvature."[1]

The second factor controlling the resistance of a tube, namely, the distance between anode and cathode, is very remarkable. Within certain limits, the current passes more easily when the two are wide apart than when close together. This was pointed out in 1884 by Hittorf, who demonstrated it by means of the tube shown in Fig. 35. When this is highly exhausted, and a discharge passed through the electrodes, which, it will be noticed, are very close together, the direction taken by the discharge is not straight across, but the longer track through the spiral tubes, showing thus that the longest way round is the path of least resistance.

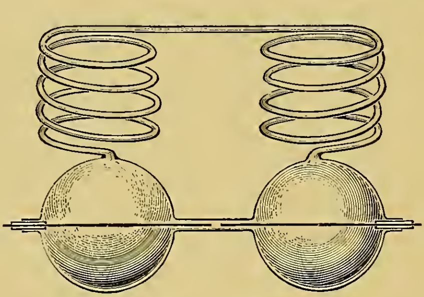

FIG. 35.—Hittorf's Experiment.

In the description of the effects of different vacua on the discharge given on page 8, attention was called to the dark space

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[1] *Archives of the Roentgen Ray*, ii., 45.

which, at a certain stage of exhaustion, immediately surrounded the cathode. This space has been shown to have an exceedingly high resistance, so that a discharge can scarcely be forced from the cathode to a positive terminal placed within the space, whilst the current passes with comparative ease when the anode is removed to a greater distance.

This knowledge has been made use of in the construction of two different tubes, *viz.*, the Penetrator and Mr. Swinton's adjustable tube.

The Penetrator Tube.—This, according to Mr. Lewis Wright, was originally of German manufacture, but is now made in England by Messrs. Newton & Co. It is shown in Fig. 36.

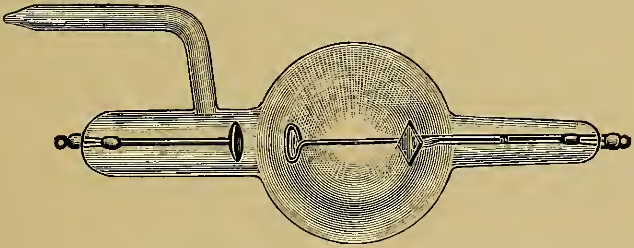

FIG. 36.—Focus Tube: Penetrator Type.

The platinum reflector is not the anode, *although it can be used as such*, the positive terminal of the coil being connected to a ring-shaped aluminium anode, which is much closer to the cathode than the reflector. This increases the resistance and penetrating power of a tube which is of comparatively low vacuum, whilst at the same time keeping the reflector sufficiently far from the cathode to allow the molecular stream to focus in a fine point on its surface.

Adjustable Tubes.—Mr. Swinton designed tubes with adjustable anodes, but as these had the disadvantage of altering the position of the actual source of X rays within the tube, he abandoned their use, and designed one with an adjustable cathode. It is thus described by its designer: The tube "depends for its action upon the fact that the resistance of the tube and the penetrative value of the X rays that it generates can be greatly varied by altering the radius of the annular space between the edge of the cathode and the glass of the containing bulb. In this tube the anticathode is fixed, but the cathode is mounted upon a steel rod, held in guides, so that by gently tapping the tube the cathode can be moved to a small extent—say about one half of an inch—in and out of an annex blown on one side of the glass bulb. The shape of the walls of the annex are such that when the cathode is at one end of its travel, and as far as it can get from the anticathode, the edge of the cathode is very near the glass all round, while, as the cathode is moved nearer to the anticathode, the annular space between the cathode edge and the glass becomes larger and larger, until at the other end of the travel the cathode emerges from the annex into the bulb itself. With a tube of this construction, the greater or less proximity of the glass to the cathode is found to have a much larger effect in increasing or decreasing the resistance of the tube and the penetrative value of the X rays than the contrary result that would be occasioned by the alteration in the distance between cathode and anticathode. A travel of one half of an inch is sufficient to alter the X rays from the highest to the lowest penetrative value, and between the limits of travel any desired degree of penetrative value is immediately obtained."

Tubes in which the Vacuum may be Altered.—Mention has already been made of the fact that the vacuum of a tube which has gone hard by constant use may be lowered by reversing the current; and a tube has been described (page 95) in which a special aluminium anode enables this to be done without undue blackening. Other tubes have been designed from time to time for effecting this lowering of vacuum in various ways.

Crookes used a tube to demonstrate the effects of varying vacua, in which he obtained slight variations by heating a piece of caustic potash. This gives off a minute trace of water vapour, thus lowering the vacuum. On cooling, the vapour is slowly reabsorbed.

To use this in a focus tube a small annex containing the potash is sealed to the tube so that the tube and annex communicate by a small aperture. When the tube has hardened, a slight application of heat will soften it again. This arrangement is, however, very difficult to manage, as the changes caused by the potash are too great for practical purposes.

Another method is to fill the tube with hydrogen gas before exhaustion, and place a piece of metallic palladium in the annex. The application of warmth to the palladium liberates occluded hydrogen and lowers the vacuum of the tube. This has the same defects as the last.

Messrs. Watson & Co. have designed a complicated form of focus tube in which the annex is arranged so as to form a parallel electrical circuit with the main tube, excepting for an adjusted spark gap. When the resistance of the tube is too high, the current, instead of passing through it, leaps across the spark gap, and heats the substance within the side tube, thus giving off vapour until the vacuum in the focus tube has fallen to the desired extent; after this the current resumes its natural course, and an occasional spark, which passes automatically, keeps the tube in a constant condition.

Such complex tubes are, however, best left alone, at any rate by the beginner in X ray work. Many of the ablest experts turn out their best work with the simpler forms of tube, which may be controlled for all practical purposes by judicious heating.

Tubes for very High Pressure.—When the Wehnelt electrolytic break was first introduced and used with comparatively large currents, many workers found that the increased power of their coils had a very destructive action on tubes. The anode of a low-resistance tube becomes white hot very rapidly when worked with a powerful coil; and if the anode be thin and the rays very accurately focalised, a hole will soon be melted through the platinum, thus completely destroying it. In other cases the cathode stream bends the anode and impairs its power of giving a sharp image on the screen. A high-resistance tube is not so readily destroyed, but will not long resist the discharge from a large coil with a Wehnelt interrupter.

To overcome this difficulty, and to take full advantage of great penetration obtained with high tension currents, two methods have been adopted. One is to conduct the heat away from the anode as rapidly as possible, and the other to make the anode of some substance having so high a melting-point as to be practically infusible.

Cold Anticathodes.—Two types of tube are in use which keep cool during excitement. The first has its anticathode made of a large mass of metal (copper faced with platinum), so that the heat may be rapidly conducted from the platinum face and radiated from the large surface of metal. The second has a hollow platinum anode, which can be filled with water. When in use the evaporation of the water keeps the tube cool.

Metals with High Melting-points.—The following table gives, side by side, the melting-point in degrees Centigrade, and the atomic weights of various metals. The power which a metal has of utilising the energy of the cathode stream for the effective production of X rays appears to be a function of the atomic weight, those with a high atomic weight working most efficiently. Hence, in selecting a metal, both the factors given in the table must be taken into consideration.

Metal.	Melting-point.	Atomic Weight.
Osmium	never fused	190·3
Ruthenium	a little higher than iridium	101·4
Iridium	2,500 (Pictet)	192·5
Uranium	bright red heat	240
Thorium	not determined (burns at high temperature)	232
Platinum	2,000 (Deville); 1,500 (Violle)	197
Palladium	1,700 (Pictet); 1,500 (Violle)	106·3
Gold	between 1,030 and 1,381— 1,045 (Violle); 1,240 (Riesendyck)	196

Osmium has a very high atomic weight, is the most infusible of known metals, and has a higher specific gravity than any other known substance. Although it has never been fused, it may be volatilised in the electrical furnace at a temperature somewhat beyond the melting-point of iridium.

It has been used for high-class tubes, but as it is very difficult to obtain, it has been customary to set a small piece of the metal in an anticathode of platinum, solidly backed with aluminium.

Such tubes are, however, hardly a commercial article on account of the rarity of metallic osmium.

Iridium, with its high melting-point and atomic weight, is used considerably, and tubes having a piece of this metal set in the anticathode may be readily obtained, though their price is high, and varies from time to time.

Uranium is not a commercial article, but Sir William Crookes has used it as an anticathode, and found it to work better than platinum. He also used *thorium*, but with what effect I have been unable to ascertain.

Besides the metals mentioned in the list, *chromium* has been used on account of its high melting-point, but its low atomic weight (52·4) makes it very inefficient.

The most accurate and delicate X ray work is undoubtedly the ophthalmic work of Dr. Mackenzie Davidson, who has exactly located small particles of steel in eyeball and orbit. This was done by means of his stereoscopic system described on page 123. In order to get the necessary clearness of definition, he used a tube in which the cathode stream was very accurately focused on an anode of iridium.

Penetration.—The penetrative quality of the rays given off by a focus tube depends, as has already been stated, on the resistance of the tube. There is, however, another factor which will give considerable penetration to the rays from a soft tube. That is, the power used. Unfortunately, we have at present no direct means of measuring the current passing through the tube, so that it is customary to register it by stating the number of ampères running through the primary coil. Thus, one occasionally sees the statement that a radiogram was taken, using, say 10 volts and 4 ampères, whereas the actual current used was extremely small, but had an enormously high voltage.

If a hand be examined with a screen, using a soft tube, which shows the bones as very black shadows, and the current be gradually increased, a considerable change will take place in the screen shadow. The bones will become much more transparent, as though the tube were getting harder. Thus, the penetrative power of the rays increases with the ampèrage of current used in the primary coil.

Photographic Effect.—The penetration of the rays is most usually gauged by means of a fluorescent screen. This, however, does not give us an accurate clue to the photographic effect. Mr. J. H. Gardiner has investigated the effects of tubes in different stages of exhaustion on a dry plate. He considers the general appearance of the tube to be the best criterion of its state, and describes the following five stages:—

(1) The path of the cathode rays seen in the faint gaseous luminosity comes to a focus just in front of the anticathode or target which is uniformly red hot. There is considerable gaseous luminosity round about and behind the target, the

phosphorescence of the glass is faint, and the dark zone in the plane of the anticathode is just visible. The resistance at this stage is equal to $\frac{3}{4}$ in. in air between pointed electrodes.

(2) The luminous cone from the cathode has become faint and contracted, so that it appears almost as a straight line, forming when it strikes the anticathode a bright red spot on the otherwise dull red surface. There is more phosphorescence of the glass and less gas visible. The resistance has increased to equal $1\frac{1}{4}$ ins. air gap.

(3) The cone from the cathode is no longer visible; there is a faint nebulosity in front of the anticathode; the phosphorescence of the glass is more brilliant, and the resistance has increased to $1\frac{3}{4}$ ins. air gap.

(4) The faint nebulous glow that in the last stage was seen in front of the anticathode has crept up the front and over the back, finally detaching itself from the anticathode altogether, and forming a very faint cloud behind it. The phosphorescence of the glass is at its maximum, and the platinum target is red hot only at its centre. The resistance has increased to equal 3 ins. air gap.

(5) A sudden change has now taken place. All trace of the nebulous cloud due to the residual gas has gone, the target is no longer red hot, and the phosphorescence of the glass has diminished to a quarter of its maximum intensity. The resistance has increased to equal 4 ins. air gap.

By a systematic series of exposures, taken with tubes in each of these stages, Mr. Gardiner has shown that although the luminosity of a screen increases throughout, the photographic action reaches its maximum at stage (4), which it will be noted, corresponds with the maximum phosphorescence of the glass. Hence the general appearance of a tube is an excellent criterion of the energy with which it will attack a photographic dry plate.

Red Tubes.—Any variation in the composition of the glass will cause a different coloured fluorescence when the tube is excited. This has led to various tubes being placed on the market whose only peculiarity is the colour of their fluorescence.

The only one of these having any advantage is the red tube. As stated later, when describing practical work with the fluorescent screen, the light given out by an excited tube in a dark room is often sufficient to dazzle the eyes of the operator, especially as its colour is so very nearly the same as that of the fluorescing parts of the screen. In a red light, the yellow coating of the screen is invisible, appearing black. Thus the red tubes may be used for screen work in the dark room without any special precautions being necessary to veil the fluorescent light which they give out. This is a very real advantage, as the small amount of red light present is sufficient to enable the operator to see his apparatus without dazzling his eyes to anything like the same extent as an ordinary tube.

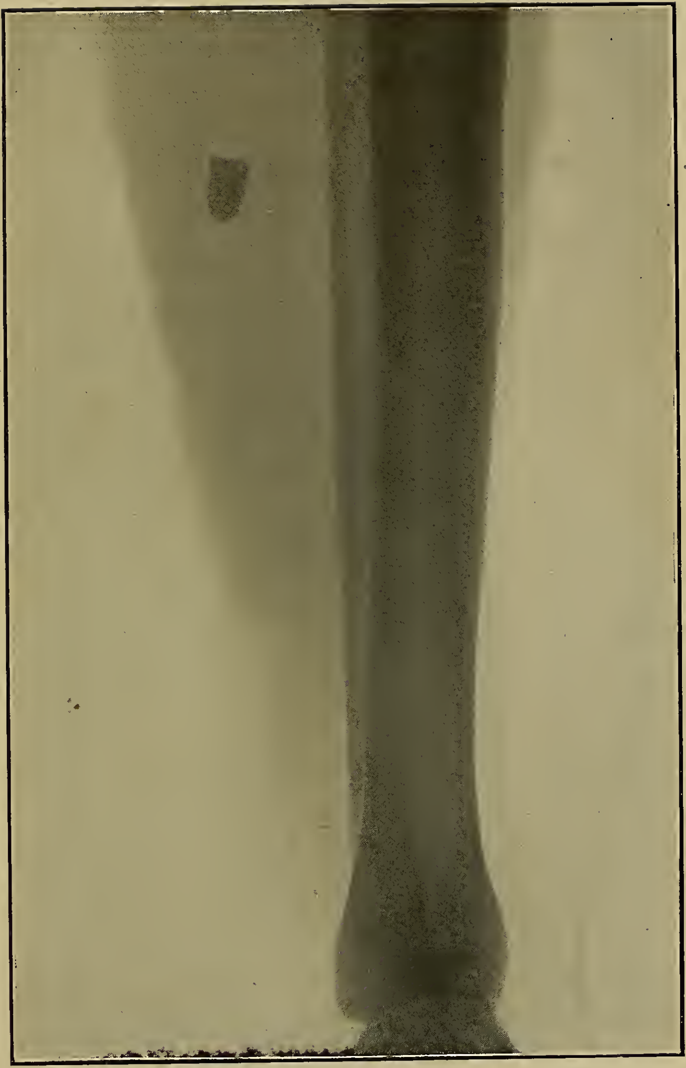

Plate III.—Revolver Bullet in Calf of Leg.

CHAPTER VI.

AIR-PUMPS.

An air-pump is more of a luxury than a necessity to the X ray worker. The judicious use of heat brings a variety of effects within the powers of a single tube, but the air-pump enables a worker to exhaust a tube to exactly suit his requirements.

Any one who has used an X ray apparatus daily for some time finds that he gradually accumulates a number of tubes which have "hardened" until their resistance is too great for the coil to overcome. These tubes are practically useless unless they are re-exhausted. This operation costs from 6s. to 10s., and is not always a success. They may be, however, re-exhausted at home, provided that a really good air-pump is at hand.

Glass-blowing. — Some knowledge of glass-blowing is essential for work with an air-pump. Only the most skilful of amateur glass-blowers could undertake the making of the focus tubes, but any one who is accustomed to delicate work with his fingers will readily acquire sufficient expertness in glass work to carry out the operations required in exhausting a tube. It would be out of place, in a volume of this size, to explain the process of opening and joining up tubes; but those who wish to do the very highest class of X ray work, and who wish to exhaust their own tubes, should obtain Shentone's *Glass-blowing*, a little book which gives all the information necessary.

Varieties of Air-pump.—There are three chief varieties of air-pump, (*a*) the old mechanical form, which is quite useless for obtaining high vacua; (*b*) the various mercury-pumps, which are nearly always used; and (*c*) the Geryk pump, which works in oil. Besides these there is a fourth variety, which is not intended for high vacuum work, but which is very useful as an auxiliary to the mercury-pumps, *viz.*, the water-exhaust-pump.

Sprengel Pump.—Mercury-pumps work on one of two principles, which may be classified as the Sprengel and the Geissler. The Sprengel is the oldest form. Mercury is poured into a glass cistern at the top of a wooden frame, and allowed to run down a vertical glass tube, turn round through a flexible rubber tube, and ascend through a second vertical glass tube until it reaches to within 20 ins. or so of the level in the cistern.

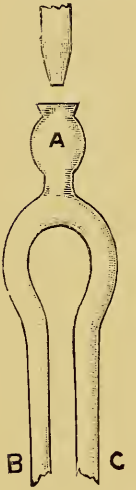

Fig. 37.—Head of Sprengel Dropping Tube.

At the top of this second tube is the working part of the apparatus, consisting of a sharp bend of the tube with an inlet above (see Fig. 37). The inlet tube, A, is connected with the vessel to be exhausted. As the mercury rises slowly through B, it runs over the bend and falls down C in drops. Each of these drops entirely closes the tube, so that a certain quantity of air is imprisoned between the drops and carried away down the tube, which is 4 or 5 feet long, the lower end dipping into a trough of mercury.

In the figure (37) a joint is shown at the point where the inlet meets the bend. The inlet tube has a ground end which fits accurately into a hole, whilst the joint so formed is surrounded by a cup, into which mercury or strong sulphuric acid is poured to render it perfectly air-tight.

The obvious defect of the Sprengel pump in this form is its extreme slowness. To overcome this, pumps have been devised with several fall tubes.

Geissler's Pump.—This pump makes use of the torricellian vacuum of a specially constructed barometer tube. Friedrich's variety of the Geissler pump is shown in the diagram

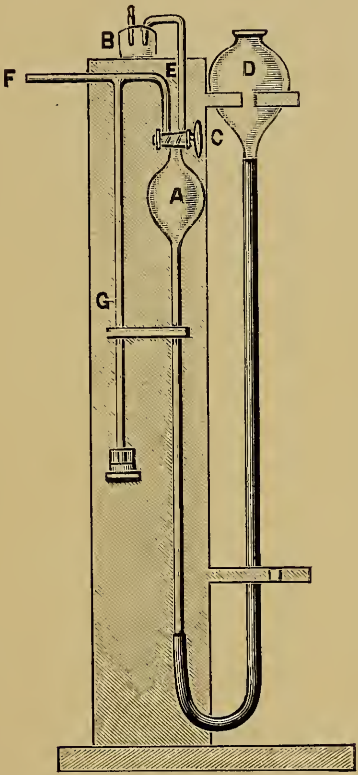

Fig. 38.—Geissler's Pump.

(Fig. 38). The only complicated portion of the apparatus is the stop-cock, C. In the position shown in the figure it connects the vessel, A, with the tube leading to B, and thence to the outer air. If it were turned through an angle of 90°, the vessel, A, would be completely closed, whilst another 90° turn would connect A with E, and thence with the gauge, G, and through F with the vessel which is to be exhausted.

To work the apparatus, it is placed exactly as in the figure, attaching the tube or other vessel to be exhausted to the open end of F. Mercury is poured in through D until it rises to such a level that A is filled, and a small quantity runs through the tap.

The tap is now turned through a right angle, D is removed from its stand, and slowly lowered until it can be placed in the lower stand. A will now be the head of a barometer tube, and as the tube is more than 30 ins. long, the mercury will fall and leave a torricellian vacuum in A. By turning the tap, C, so as to make communication with E and F, the air is allowed to run out from the X ray tube into the vessel, A.

By repeating this cycle of operations, the air may be rapidly exhausted and a very high vacuum secured. The defect is in the number of joints, all of which form possible entrances for air.

Toepler's Pump.—This form of mercury air-pump is by far the most useful for X ray work, as it works more rapidly than the Sprengel, and is free from the joints of the Geissler. Fig. 39 shows the simplest variety of pump working on the Toepler principle.

Mercury poured into the glass cistern will run down the rubber tube and rise in the upright glass tube until it comes to the first junction B. As it rises further it will come to the next junction, and then rise regularly in the bulb and the two upright tubes. The rise will go on until it reaches the escape tube, D, down which it will fall, to be caught in the little vessel below. When this little vessel is filled with mercury the cistern is lowered, and the whole upper part of the system of tubes, including the X ray tube, which has been sealed on the open end, E, will become a partial torricellian vacuum.

When the mercury in the bulb, F, has fallen below the level of the junction, B, the cistern is again slowly raised, and the inflowing mercury will first form a valve at C, stopping the way into the X ray tube, then will rise in the bulb and eject what air it contains through the fall tube. By repeating the cycle of operations a high vacuum is eventually obtained.

Very good work may be done with such a pump as this if care be taken to work slowly. The system of tubes is rather fragile, and when the vacuum is formed a sudden raising of the mercury is apt to break it.

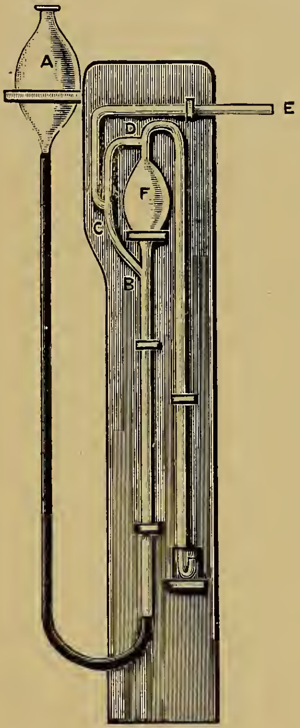

FIG. 39.—Toepler's Pump.

Mr. Wilson Noble, in carrying out a series of researches on the effects of vacua, began by using an ordinary Toepler pump, but as its defects became more and more apparent to him, added improvements of various kinds until he finally used the rather complex apparatus described below.

With regard to defects, he says:—

"In the first place air was always getting in through the india-rubber tube used for lifting the mercury, so I added an air-trap; but this was only a partial success, as the mercury still got fouled with the tube, and it is impossible to keep mercury clean as long as the tube is adhered to. I therefore determined to get rid of the india-rubber tube altogether. This I did by forcing the mercury up by means of a bicycle-pump, but it was difficult to work the pump slow enough to avoid blowing the head of the pump off. I then tried, what ought from the first to have been done, to allow the vacuum of the pump to raise the mercury and then draw it down by another vacuum. In this I thought I had made a valuable discovery, when I was fortunate enough to come across the President's[1] invaluable monograph on mercurial-pumps, when I found my new idea was as old as the hills. Another defect in the ordinary model of pump is that the mercury, after leaving the fall tube, is exposed to the air, and thus becomes contaminated with dust and moisture, and has to be transferred to the lifting reservoir, where it is again exposed to the air. I have now confined the mercury entirely within the pump, and no air whatever gets to it without first passing over calcium chloride."[2]

Noble's Modification.—Mr. Noble gives the following as the chief objects to be aimed at in designing a mercury-pump:—

(*a*) That it should work automatically.

(*b*) That it should have no rubber tubing.

(*c*) That it should have no stop-cocks.

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[1] Prof. Silvanus P. Thompson, F.R.S.

[2] *Archives of the Roentgen Ray*, ii., p. 77.

(*d*) That air should never enter even whilst tubes were being fixed for exhaustion.

(*e*) That the mercury should not come in contact with damp or dust.

(*f*) That it should be of simple construction, and easily repaired by any one with an elementary knowledge of glass-blowing.

(*g*) That it should not be liable to break, and that it should be capable of maintaining a high vacuum for a prolonged period.

The glass parts of the apparatus designed to fulfil all these conditions is shown Fig. 40. At first sight the plexus of tubing looks terribly complicated, but it is readily understood if considered as made up of three parts.

The actual air-pump is made up of the three vessels, A, B and C, and their connecting tubes. The central part consists of gauge and barometer tube, whilst the right-hand portion, consisting of the vessels, D and E, and the tubes, *h*, *i* and *k*, is an appliance for preventing the admission of air to the pump when not working.

A is the stationary vessel of the Toepler pump in which the torricellian vacuum is formed. B is the cistern which in the Toepler pump is movable.

The action of the pump is started by means of a mechanical pump, such as the Geryk, or better, a water-pump (Fig. 41). This is attached to the stop-cock, *c*, and the whole of the pump is thus exhausted to a fairly high vacuum. Mercury rises in the gauges and in *i*, but the ultimate action of the pump depends on the rise in A. From the bottom of B to the top of A is less than 30 ins., hence the mercury completely fills A and runs over down the fall tube into G.

When this happens the tap at C is turned off and is not used again. All the other taps are now attached to the water-pump, and the whole apparatus works automatically. The mercury runs down the fall tube until the bottom of A is stopped. A vacuum then begins to form by the action of the water-pump in B, which draws the mercury back from A, and at the same time causes a little to run up *a*. When sufficient

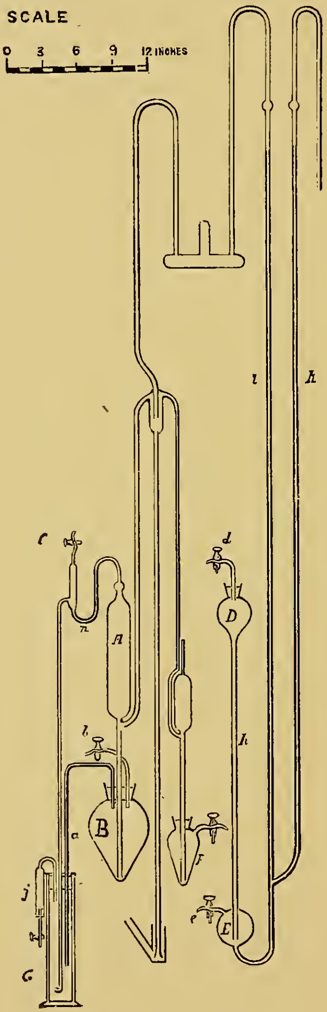

FIG. 40.—Modified Toepler Pump.

has passed up *a*, to uncover its end and let in the air, the mercury passes up again from B to A and over the fall tube. Thus the mercury rises and falls regularly without using a movable cistern. The pump otherwise acts exactly like the Toepler.

Supposing that a focus tube be attached to the open end of *k*, no exhaustion will take place whilst the tubes, *i* and *k*, are choked with mercury. This is therefore drawn off into the vessels, D and E, by attaching the stop-cocks, *d* and *e*, to the water-pump until it falls below the junction.

Finally to quote Mr. Noble's description:—

"When it becomes necessary to open *k* to attach a fresh tube, air is let in by *c*, and when the mercury has risen as far as it will in D, *c* is closed and air is let in at *d*. Mercury will now stand about two-thirds up *h* and the barometric height higher in *i* and *k*. *k* may now be opened, when mercury will fall in *k* and rise in *i*, but no air will pass by the junction of the tubes."

The Management of Mercury.—When an elaborate apparatus is used, such as that just described, mercury has very little chance of becoming soiled, but with the more ordinary forms of mercurial air-pump, it requires considerable attention.

Dust and dirt may be generally removed by running the mercury through a filter made by folding a sheet of writing-paper into a cone and pricking a small hole in the apex. The mercury will run through the hole, leaving most of the dirt on the paper. If this is not sufficient it should be squeezed through chamois leather.

Contact with an india-rubber tube, which it should be remembered always contains large quantities of sulphur and sometimes various sulphides, has a fouling action by forming small quantities of mercuric sulphide. It may then be purified by shaking up with dilute nitric acid. L. Meyer's method is thus described by Roscoe and Schorlemmer:—

"The metal is allowed to flow in a very thin stream from a small opening in a glass funnel into a wide glass tube 1·25 metres high and 5 centimetres in diameter, which contains a mixture of water with 100 cubic centimetres of nitric acid. A narrow tube is fastened to the bottom of this, from which the pure metal flows; it has then only to be washed with water and dried. The above operations may have to be repeated several times, and the metal if pure must leave no residue when dissolved in pure nitric acid and evaporated to dryness and ignited."[1]

The only absolutely sure way of purifying mercury is by distilling it. Various stills have been invented for carrying out this operation, but my experience is that it is most economical in the long run to send it to some chemical manufacturer, who has the necessary apparatus and technical skill, and get him to distil it.

Moisture.—Water is the great enemy of high vacua. At the ordinary temperature, about 60° F., it exerts a vapour pressure equal to 12·7 millimetres of mercury. Therefore it is of the highest importance that both the mercury and the tubes of a pump shall be perfectly dry. Precautions must also be taken to prevent the introduction of moist air.

In Noble's pump each tap is protected by a tube containing calcium chloride, so that any air having access to the mercury will be quite dry.

In most pumps a vessel containing phosphorus pentoxide is placed between the focus tube and the pump. In some cases very elaborate drying apparatus is used, but complications, as a rule, introduce more joints, and thus increase the possibility of leaking.

When using desiccating substances, it must be remembered that calcium chloride and other substances which absorb water in

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[1] *Treatise on Chemistry*, vol. ii., part i., p. 392.

the form of water of crystallisation should never be introduced *inside* a vacuum, as they would then be apt to give off the water which they had absorbed. Phosphorus pentoxide combines directly with water to form phosphoric acid, which is perfectly stable in vacuo.

Water-pumps.—These simple but effective little instruments are made of either glass or metal, and are largely used by chemists to assist filtration. A glass filter-pump is shown in Fig. 41. To set it in action, the upper end is attached by stout india-rubber tubing to a high-pressure water-tap and the water allowed to run through it. The high speed of the water will reduce the pressure inside the bulb and carry air away down the lower tube. The side tube is connected with the vessel which is to be exhausted.

Some care is necessary in making the joint between the tap and the top of the pump. A very good method is to make the joint first with rubber tubing, bringing the tap and pump close together, then to wire the rubber on tightly with fine copper wire. Next the joint should be well wrapped up with strong tape, and wired again.

The chief use of this pump is to start the exhaustion of a tube, or to assist such a pump as Noble's form of Toepler.

Joining up the Tube.—To join a tube to the mouth of a mercury pump of course requires a slight knowledge of glass-blowing, and even with this knowledge it is a little puzzling at first sight to see how it can be accomplished. The diagram (Fig. 42) shows a simple method of overcoming the difficulty. P is the tube leading to the pump. Instead of joining the side-piece of the focus tube directly to this, it is first joined to the side of an extra piece of tubing, J A, and drawn out fine at M and N. The joint is then made at J.

Before starting the mercury-pump, A is joined to a water-pump or a mechanical air-pump, which removes most of the air in a minute or so. When the gauge shows that a good vacuum has been formed, A is drawn off, and the tube sealed at M. The mercury-pump now comes into action, and the focus tube is tested from time to time by passing the current through it and observing the appearance of the discharge. When the tube begins to fluoresce under electrical excitement, it will need heating to help the pump. An Argand burner is very useful in the earlier stages, but later on a Bunsen burner should be used, applying the flame directly to the tube, but keeping it constantly moving so as to avoid cracking or softening the glass.

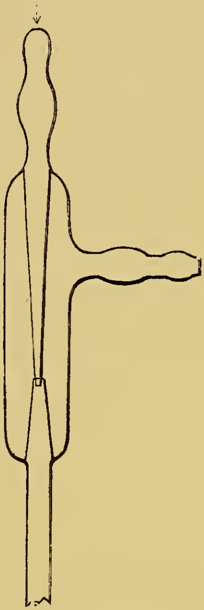

FIG. 41.—Water-pump.

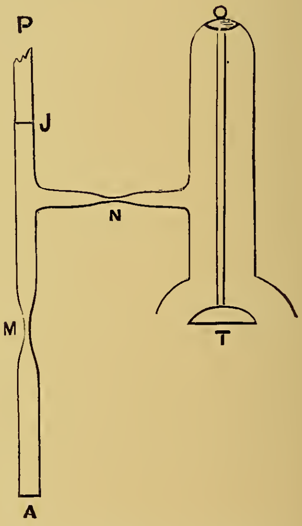

FIG. 42.—Method of attaching Focus Tube to Air-pump.

To judge of the resistance of the tube, it must be allowed to cool before passing the spark.

CHAPTER VII.

TUBE HOLDERS AND STEREOSCOPIC APPARATUS.

Requirements.—In selecting some form of stand to hold the focus tube in position during an operation, the following points should be borne in mind:—

The tube should be held rigidly, so that it cannot move during exposure. Any movement, caused either by slipping or the vibration of the contact breaker, will blurr the picture.

The stand must have sufficient joints to allow of the tube being held in any position. Usually a radiogram is taken by laying the part over a properly enclosed photographic plate, and holding the tube over it, but for screen work it is often necessary to turn the tube sideways, or even to put it under a couch.

There must be some arrangement for keeping the wires well apart during the operation, or the current may spark across from one wire to the other, instead of running through the tube.

Stands Resting on the Floor or a Table.—The simplest form of stand consists of a stout upright standing on a heavy foot, and carrying a long movable arm, at the end of which is a clip. The wires are kept apart by being led through eye-holes at the ends of a crossbar. Such a stand is useful in a consulting-room, but is very awkward to carry about.

A somewhat similar stand, constructed on a smaller scale, may be placed on a table when in use, and though much more portable, is also more limited in its usefulness.

Stands Attached to Portable Apparatus.—A stand which I have always found to work well consists of three brass telescopic tubes supporting a clip, with universal motion. It is fixed by a clamp either to the bed or couch on which a patient lies, or to the table on which he places his arm or hand; or it may be attached to the waggon on which the apparatus is carried (see Fig. 47). It is very portable, but when drawn out to its fullest extent, is not very rigid.

On some portable apparatus a wooden stand is fixed by means of a screw. This is, as a rule, more rigid, but has less freedom of movement.

Stereoscopic Stands.—Mention has already been made of the Davidson system of stereoscopic photography, in which two different photographs are taken with the tube in slightly different positions. Negatives are thus obtained by means of which the position of a foreign body may be localised with mathematical accuracy, and from the negatives may be obtained prints which, when viewed through a stereoscope, show the parts standing out in their natural relationship, or as nearly so as the distortion of the shadows will allow.

To place the tube first in one position and then in another at a known distance from the first, and yet in the same horizontal plane, necessitates the use of graduated apparatus.

Sometimes the stereoscopic stand is attached to a special form of couch (see below), but there are several portable forms. The most usual consists of two upright pillars placed one on each side of a couch, and a graduated boxwood cross-piece fixed across them. On the cross-piece runs a sliding clip, which may be fastened firmly in any position. Such a stand is very rigid, and most useful for all kinds of X ray photography. For screen work it is not so well adapted; but screen work does not, as a rule, necessitate such great rigidity in the stand, so that one of the forms described above fulfils all requirements.

Stereoscopic Couch.—For accurate stereoscopic work, and for Dr. Davidson's system of localising foreign bodies, something more is required than a rigid holder. When two photographs are to be taken of the same part of the body, with the focus tube in slightly different positions, it is necessary to have some means of changing the plates without altering the position of the subject. Further, some sort of mark must be made on the plate, which will enable the finished photographs to be accurately registered for viewing through the Wheatstone stereoscope.

The most complete apparatus is the couch devised by Dr. Mackenzie Davidson. Fixed to the sides of the bed are two uprights and a graduated cross-piece, arranged as in the stand last described. Sliding along the cross-piece is a clip for holding the tube.

Underneath the centre of the bar is a gap in the cushioning of the couch, and flush with the upper surface of the cushions is a square frame large enough to hold the largest plate likely to be used. Over the frame is a tightly stretched sheet of vellum. Below this is an arrangement for sliding in the plate, enclosed in a black envelope.

To ensure accurate registration two thin lead or platinum cross-wires are strained across the vellum, one running parallel to the cross-bar of the stand and exactly beneath it.

In working with this apparatus the patient is placed on the couch in such a position that the part to be radiographed lies on the vellum. The tube is first adjusted by means of a plumb-line, so that its anode is perpendicularly above the intersection of the cross-wires. Sliding-pieces are now clamped on the graduated bar at equal distances on either side of the clip, so that it may be free to slide about 2 ins. in either direction. It is run along until stopped by one of these pieces. A plate is inserted beneath the vellum, and the exposure made. Then, without moving the patient, the plate is removed and a fresh one inserted, the clip is run back until stopped by the other sliding-piece, and an exposure made with the tube in the new position.

The distance apart of the two positions of the anode should be about 2½ ins., with the tube 20 ins. away from the plate.

Wheatstone's Stereoscope.—A convenient means of viewing these photographs is the Wheatstone's stereoscope, consisting essentially of a stand which holds the two prints facing one another, about 18 ins. apart, and two mirrors set perpendicularly at right angles to one another between the photographs. The arrangement is shown diagrammatically in Fig. 43. E and E_1 are two eyes looking into the plane mirrors, M and M_1. The eye E sees the print P, whilst E_1 sees P_1, with the usual stereoscopic effect that the parts shown in the prints stand out in their natural positions.

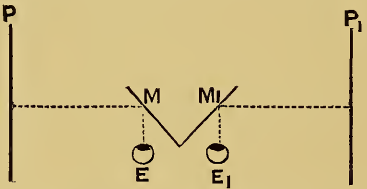

Fig. 43.—Diagram of Wheatstone's Stereoscope.

Davidson's Localiser.—Beautiful as are the results of Davidson's stereoscopic system, the greatest utility of the couch and stand is in the accurate localisation of bullets, needles and other foreign bodies, even such minute particles as steel filings in the eyeball.

It is easy to see how by careful measurements of the distances of the images of the foreign body from the shadows of the cross-wires in each photograph, a mathematical calculation can be made showing the exact position and size of the body, including its distance beneath the surface.[1]

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[1] Mr. Ernest Payne suggests a graphic method. He says (*Archives of the Roentgen Ray*, vol. ii., p. 31):—

"Let us first consider a theoretical case. Referring to Fig. 44, let AB be a

The Davidson localiser does away with any need for mathematics.

Two photographs are taken on one plate from two positions of the tube, which are accurately measured by the stereoscopic stand. After development a double image of the foreign body is shown, but only one image of the lead cross-wires. To utilise the negative so obtained, a cross-thread localiser is used, which Mr. Davidson describes thus:—

"A sheet of plate glass is fixed horizontally, having two lines marked upon its surface crossing at right angles in the centre. A mirror hinged below it allows the light to be reflected from below so as to render details of the negative placed upon the sheet of glass visible by transmitted light.

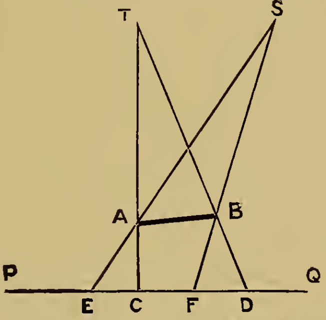

FIG. 44.—Graphic Method of Localisation.

hidden object, the size and position of which we wish to know. If we take a radiogram with a tube, T, we shall obtain a shadow, CD, on a plate, PQ, placed below the object; if we move the tube to another position, S, we shall obtain another shadow, EF. Then if we draw lines from T to C and D, the extremities of the first shadow, and from S to E and F, the extremities of the second shadow, TC and SE will cut one another at A, and TD and SF will cut one another at B. Conversely, therefore, if the positions of S and T are given, together with the dimensions of the shadows, we can determine the position and size of AB.

"In actual practice graphic methods may be employed, the drawings being made full size or to scale, so that no trigonometrical calculations are needed, and the dimensions can be taken direct from the drawing."

It should be noticed that *plane* geometry is used in this method, so that care must be taken to make the line of displacement of the tube lie in the same plane as the needle and its shadow, or errors will be introduced.

"A scale fastened to a horizontal-bar slides up and down on two rods which support its ends. The scale has small notches opposite its marks. This is so placed that a perpendicular dropped from the 0 or middle point of the scale tells exactly where the lines cross on the glass stage. Further, the edge of the scale is parallel to the line running right and left on the glass.

"The negative is now placed on this glass stage, being careful to bring the shadow of the cross-wires into register with the cross on the stage, and placed with its marked quadrant in correct position. The gelatine surface can be protected by a thin transparent sheet of celluloid.

"The scale is now raised or lowered so as to bring the 0° to precisely the same distance above the negative as the anode of the Crookes' tube when the negative was produced. All that is now necessary is to place a fine silk thread through the notch on one side of 0 of the scale and another thread through a notch on the other side, exactly the same distance apart as that which measured the displacement of the X ray tube.

"Small weights are attached to the ends of the two threads to keep them taut, while the other ends are threaded into fine needles fastened to pieces of lead. Thus the needle with the thread can be placed on any point of the negative and remain in position. In short, the negative is now relative to the cross-lines, the scale and the notches from which the two threads come, exactly the same as it was to the cross-wires and Crookes' tube when being produced.

"A needle with the thread is placed upon any point on one of the shadows of the foreign body, and the other needle is placed upon a corresponding point in the other shadow, and it will be found that the threads cross each other, just touching and no more. The point where they cross represents the position of the foreign body."

To measure off the position of the foreign body thus revealed, one or two subsidiary pieces of apparatus are found useful. Mr. Davidson uses a brass needle mounted on a solid stand in such a way that its point can be fixed at any desired height, and an upright millimetre scale. The needle-stand is placed on the negative, and moved until the point of the needle just touches the crossing of the threads. It is then turned round bodily so that the height at which the needle point stands is measured off on the scale.

The distance from each cross-wire of the foot of a perpendicular dropped from the crossing-point to the plate is measured with a pair of compasses, and the three measurements noted thus:—

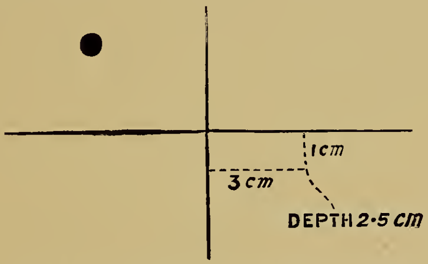

FIG. 45.—Davidson's Localisation Diagram.

If at the beginning of the operation the lead-wires have been inked, they will leave a cross on the skin of the patient, from which the position of the foreign body may be found.

Payne's Tube-holders.—In all the holders described so far, some part of the tube is firmly gripped by some form of spring or screw clip. Mr. Payne always suspends his tubes on glass hooks. Two of these hooks are bound tightly to a horizontal strip of wood by means of rubber bands, and the tube is placed in the cradle so formed. The strip of wood may be fixed to any convenient form of stand. Another form for a special purpose is described on page 146.

CHAPTER VIII.

FLUORESCENT SCREENS.

Fluorescent Substances.—In Roentgen's original experiments the fluorescent material used was platino-cyanide of barium, whilst in Lenard's earlier work the substance was pentadecylparatolyl ketone. Mr. Herbert Jackson uses a hydrated platino-cyanide of potassium, whilst after a long series of experiments Edison selected calcium tungstate. Another substance, which has the advantage of being readily prepared pure, is ammonium uranium fluoride. In par. 6 of Roentgen's first paper he states:—

"The fluorescence of barium platino-cyanide is not the only recognisable phenomenon due to X rays. It may be observed . . . that other bodies fluoresce, for example, phosphorus, calcium compounds, uranium glass, ordinary glass, calcspar, rock-salt, etc."

The substances chiefly used at the present day are the platino-cyanides of barium and potassium, tungstate of calcium, and uranium ammonium fluoride.

Barium Platino-cyanide.—This is the substance most commonly used in England. Messrs. Johnson & Matthey now prepare it in a state of great purity, and make screens by spreading it on cardboard, or better, vellum, which give very great brilliancy, though others, notably those of Kahlbaum give rather better definition with a certain loss in brightness.

The chemical composition of the substance is set out in the formula $BaPt(CN)_4 + 4H_2O$, and it may be prepared by passing hydrocyanic acid gas through a mixture of water, platinous chloride and barium carbonate. The hot mixture is filtered, and the clear solution on cooling deposits large rhombic crystals.

Unfortunately, these crystals are too coarse in texture to spread nicely over a screen, and if they are ground up they lose a great deal of their fluorescing power.

Finely crystalline powder may be purchased from chemical dealers in a fair state of purity at about £2 per oz.

Screens of this material are certainly best purchased from a manufacturer, and when injured should be repaired by the firm that originally made them. Still, amateur-made screens often work very well, though they are much more easily made of the uranium compound described below.

Barium platino-cyanide gives a greenish-yellow fluorescence under the X rays, almost identical in colour with the fluorescence of the glass of the tube.

Potassium Platino-cyanide.—This salt is used both by itself and mixed with the barium compound. It has the drawback that it ceases to fluoresce when it has lost a portion of its water of crystallisation, so that screens which are prepared with it are usually covered with some waterproof varnish. Its chemical formula is $K_2Pt\ (CN)_4 + 12H_2O$, and it is prepared by dissolving ammonium platinic chloride with caustic potash in a strong hot solution of potassium cyanide; on cooling, the salt crystallises out. It fluoresces with a bluer light than the barium salt, but not quite so brightly. It is claimed in its favour that screens prepared either with the potassium salt alone, or with a mixture of the potassium and the barium salts, can be made to give more accurate definition of an X ray shadow than with the barium salt alone.

Calcium Tungstate.—When the X rays fall on either of the two salts just described they *fluoresce*, that is to say, they transform a part of the energy of the rays directly into light. Calcium tungstate has the same property in a smaller degree, but it also *phosphoresces*, that is to say, it stores up a certain amount of the energy, and gives it out as light after the rays have ceased their action. This has the peculiar effect of giving a slightly persistent image on a screen made of the substance, so that the shadow of such an object as a moving joint is blurred.

For coating a screen calcium tungstate must be crystalline. When first it was suggested for this work, much disappointment was caused to amateurs, who coated screens with precipitated calcium tungstate, a substance readily prepared in a chemical laboratory.

The crystalline substance is found naturally as the mineral scheelite in many parts of the world. In England it occurs at Caldbeck Fall, in Cumberland. It is prepared by mixing solutions of calcium chloride and sodium tungstate, mixing the precipitated substance with lime, and heating it strongly in a current of hydrochloric acid gas.

Its formula is $CaWO_4$, and it fluoresces with a bluish light, which is far more actinic than that of the platinocyanides, hence it is used for intensifying screens (page 131).

Uranyl Ammonium Fluoride.—This salt, which fluoresces well, is very easily prepared in the laboratory. Strong solutions are made of uranyl nitrate and ammonium fluoride. The two solutions are mixed, using 6 parts by weight of ammonium fluoride to 1 part of uranyl nitrate, and well shaken. A fine crystalline precipitate quickly forms. This is filtered, washed with alcohol and dried. It is insoluble in ammonium fluoride solution, but soluble in water, and has the chemical formula $UO_2F_2 . 3NH_4F$.

Supports for Chemicals.—The supports originally used for the fluorescent chemicals were generally made of cardboard. Nowadays various substances are used. The most serviceable is a piece of vellum stretched on a wooden frame. One side is coated with the chemical, whilst the other is blackened. Frequent use is apt to soil the back of the screen, and it is as well to have it made of some material which may be washed without injury.

Some screens are mounted on waterproof material, such as rubber, and are purposely made flexible. It is conceivable that circumstances may arise in which a flexible screen may be useful. Often, no doubt, such a screen might be closely applied to some part of the anatomy, and thus give a clearer image than could be obtained on a flat screen; but, as a rule, the shadow on a flat screen, which is a simple conical projection, will be found quite difficult enough to diagnose without any further complications. The distorted shadow on a curved screen should not be used if it can be avoided.

A very flexible screen is, however, useful as an intensifier.

Intensifying Screen.—Very soon after the introduction of X ray work attempts were made to reduce the times of exposures by placing some fluorescing material on the photographic plate. Roentgen thought it quite possible that the photographic effect on a plate was "due to the fluorescent light which . . . may be generated in the glass plate, or, perhaps, in the gelatine," so that it was quite natural to use some means for increasing the light. Mixing fluorescent materials with the emulsion of plates has had no good effect, and the best results have been obtained by placing a flexible screen face to face with the plate. It need hardly be said that the screen must be as near as possible, as theoretically perfect results can only be obtained when film and screen are in optical contact.

If the platino-cyanides were used, an isochromatic plate would be necessary, as the light given by them is only slightly actinic. I have not come across any detailed statements as to the use of different emulsions, but my experience with isochromatic plates is that they are very much slower for X rays than those which have not been isochromatised.

A calcium tungstate screen works well, but it seems to be very difficult to coat it so evenly as to be free from visible grain. This affects the plate and gives a granular photograph.

If the object of the radiographer be to obtain an artistic picture, or a radiogram showing fine structural details, then an intensifying screen would be a mistake. But in most cases a surgeon wants a bone shadow which will help him to a rapid diagnosis. Here rapidity of exposure may be valuable, and seeing that a calcium tungstate screen will reduce the exposure to one-fifth of that required by the unaided plate, it is astonishing that it is not more used than it is.

Fluorescopes.—The fluorescent light given out by a screen, even when acted upon by the most powerful X ray apparatus, is very small, and can only be seen when all other light is excluded.

The best work is done in a dark-room, but various arrangements have been invented for excluding the light from the immediate vicinity of the plate. A very convenient form consists of a leather camera bellows with the screen fixed tightly at one end, whilst at the other is a fur-edged aperture against which the eyes may be placed. As a rule, it will be found that these instruments are much too long, and it is as well to order one either with collapsable bellows, or else made so that the eyes come up to the nearest point of distinct vision (say 8 ins.) from the screen.

The name "fluorescope" was given to this piece of apparatus by Edison, and Salvioni gave the name "cryptoscope" to a similar arrangement, whilst Seguy calls his form the "lorgnette humain".

Care of a Screen.—To keep a screen free from dust and scratches, a good system is to cover it with a plate of photographic glass. This in no way impedes the view, and has the extra advantage that outlines may be drawn upon it with the yellow pencils used in chemical laboratories for drawing on glass.

Calcium tungstate intensifying screens are very liable to become soiled as they are carried into the photographic dark-room. Great care should be taken in handling them, as dirty finger-marks on the surface will give constant reminders on the plates. It is as well to keep them when not in use in a special dark slide (see page 157).

Stereoscopic Screens.—Davidson's success in producing stereoscopic radiograms has led to various attempts at producing screens to show stereoscopic shadows. There seems to be only one method of accomplishing this object, and Mr. Davidson is the only one who has applied the method with any approximation to success.

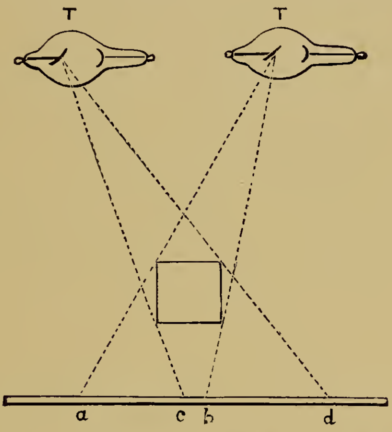

FIG. 46.—Formation of Stereoscopic Shadows.

Shadows are thrown on a screen from two tubes placed a few inches apart. The tubes are so arranged that they work in alternate flashes, a momentary current passing first through one, then the other, and then back again. These shadows are viewed through an apparatus which cuts off the view of each eye in turn whilst opening up the view of the other. Thus in the figure (46), if TT be the tubes, then when the flash passes through the right-hand tube the shadow, *a b*, is seen. When the left-hand tube gives out the rays, the shadow, *c*, *d*, will appear. But each eye will retain the impression of the shadow during the short period of blindness; therefore, the total effect is to give a different point of view to each eye, and a stereoscopic shadow.

The practical difficulties in designing such an apparatus are very great. Mr. Davidson uses two coils with mercury contact breakers. These breaks are both worked by the same motor, so that the break comes alternately in the two coils. To give the alternating vision, the screen is viewed through a pair of eye-holes, behind which a large perforated disc is rotating. The perforations are so arranged that when one eye-hole is shut the other is always open.

The results obtained when once the instrument is synchronised and adjusted are remarkably good, but in its present state it is hardly suited to the use of the general practitioner.

PART III.

PRACTICAL X RAY WORK.

CHAPTER I.

INSTALLATIONS.

The essential parts of an X ray installation are the battery, the coil, the tubes and tube stand, the screen, and supplies of wire and photographic materials. In country places, where there is a difficulty in obtaining a supply of electricity, a Wimshurst or Holtz machine may be used instead of the battery and coil. Many instrument makers advertise complete sets. Both the composition of the sets and the prices vary through wide limits. Probably the cheapest installation which will give good results, consisting of a 6-in. spark coil, with two tubes, tube holder and accumulator and screen, will cost about £25, though the most famous makers charge this amount for the coil alone. A Wimshurst machine which might be substituted for this sized coil will cost about £20.

With a small installation such as this a very large amount of work may be done, in fact anything excepting the photography of pelvic region of adults. In some cases, however, a rather long exposure will be required.

Hospital Installations.—Where every kind of work has to be done a very complete installation is required. No two hospitals have the same arrangements, but it seems to be generally agreed that a 10-in. coil is the smallest that will fulfil all requirements, and at the same time the largest that can be conveniently moved about. Such a coil with the essential accessories will cost from £40 to £60, but when means for charging the batteries or working from the mains, localising apparatus, spare batteries and tubes, carriages for the coil and battery and so forth are added, the cost is considerably increased.

Two distinct types of hospital installation are in use—stationary and portable, many hospitals of course using both.

Stationary Apparatus.—Where patients can be brought to the apparatus a great deal of trouble is saved, and more efficient work can usually be accomplished. Although a portable form of Dr. Mackenzie Davidson's stereoscopic couch is made, the original form is much more rigid, and the best work on this system can only be done with stationary apparatus. A heavy coil giving up to 20-in. spark with a mercury break may be fixed permanently on a table together with rheostats and measuring instruments. Or, if it be preferred to have a switch-board fixed to the wall, the coil may be placed on a shelf and permanently connected with the electric lighting mains. Most makers advertise some special form of stationary installation in their catalogues. It is as well, however, when setting up a heavy X ray plant to have it designed to meet the special conditions under which work is to be performed.

To develop its full usefulness, the apparatus should be set up either in a dark-room or in a room which may readily be darkened so that screen work may be carried out at any time.

Portable Installations. — Great ingenuity has been expended in devising portable apparatus. Even the small apparatus mentioned at the beginning of the chapter is very heavy, and a large coil in addition to its weight is a very awkward thing to carry about. In an hospital it may be placed on some kind of carriage, but for moving from house to house, or for military purposes, it must be fixed in a case.

All the different carriages which I have come across have one great objection—their wheels are made too small. Constant moving about, especially in and out of lifts, always causes a certain amount of jolting which is less apparent when large wheels are used than with even the most perfectly tyred small wheels.

When the coil and accessories are fitted into a portable case, it is out of the question to increase the weight by the addition of a battery. Hence battery and coil must be carried separately. Fig. 47 shows a 10-in. coil set in an oak case which opens at the top and ends and has folding discharge rods. Its dimensions are 2 ft. 5 ins. × 10 ins. × 12 ins., and it weighs about 60 lb.[1]

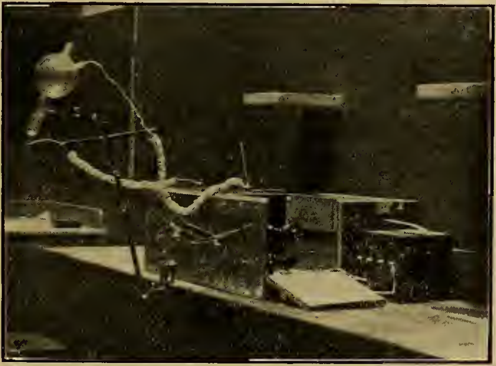

Fig. 47.—Portable Coil.

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[1] The coil of which this is a photograph was made for me by Mr. Leslie Miller, and is similar to one supplied by him to the military hospital at Omdurman.

CHAPTER II.

RADIOSCOPY.

Arranging the Apparatus.—A screen examination is somewhat simpler than the taking of a radiogram, although the arrangement of the apparatus is very much the same in both cases. In this chapter a description will be given of the methods of working with a screen.

First of all, the battery must be connected with the coil. In some installations it is left connected, and only removed when necessary for charging. This is not advisable, as one of the sources of leakage in a secondary battery is short-circuiting across the surface of the wood between the terminals. If these terminals be connected by partially insulated wires to other terminals (those of the coil), which are very close together, there is an additional opportunity for leakage. In installations set up on movable waggons these wires often run close together over wooden surfaces, across which further leakage may take place, especially in damp weather. It is therefore just as well to always disconnect the wires when not in use, and the disconnection should always be made by releasing the wire from the battery terminal.

Both the battery and the coil terminals are marked, so that there is no difficulty as to the connections. Indeed, it matters very little how they are made, as the current can always be reversed by the commutator. Usually the + of the battery is connected with the P of the coil, and the – to the N. If measuring instruments be inserted, the connections should be + (battery) to + (ammeter): – (ammeter) to P (coil); N (coil) to – (battery). This set of connections must be made with stout wire (10 or 12 B.W.G.), or a flexible wire with many strands. The wire should *not* be closely coiled up, as this only increases the resistance due to self-induction, but should be as stout as convenient, and as far as possible in straight lines.

The focus tube is connected with the terminals on the discharge rods of the coil. Here a fine wire is sufficient (30 to 36 B.W.G.), but it must be well insulated. Self-induction is negligible, so the wire may be wound into a coil before attaching. The best method of doing this is to wrap an ample length of the wire tightly round the rod, about half an inch in diameter. On withdrawing the rod, not only has the wire a neater appearance, but it has sufficient elasticity to allow for any movements of the tube and stand which may be made whilst getting the tube into position. It is always a nuisance to find that your wire is too short, and if too long, and uncoiled, it is apt to spark across by coming into contact with some conducting substance.

Some operators use heavily insulated cables specially constructed for this work, which cannot be coiled, but a careful worker will find a thin wire insulated with gutta-percha all that he requires.

With an Apps' coil, and with most others, the discharge rod nearest to the commutator becomes negative when the handle of the commutator is moved over so as to point outwards from the coil—that is, if the connections between battery and coil have been made properly. This rod should, therefore, be connected with the concave cathode of the focus tube, whilst the other one is joined up with the anode.

The whole apparatus is now in working order, and on turning the commutator into the position just described, one of three things happens :—

(*a*) *No Current Passes.*—In this case the contact breaker is probably not in working order, and should be regulated by the tension screw until the platinum contacts come together, and one of the other two results is caused.

(*b*) *Sparks Leap Across Between the Discharge Rods.*—Thus showing that the resistance of the air between the points of the rods is less than that of the tube. In this case turn off the current by means of the commutator, draw the rods a little farther apart, and then re-establish the current. This operation may have to be repeated several times before the desired effect is obtained. If, when the points of the rods are as far apart as they will go, the spark still passes through the air, the tube is too hard for the coil, and must be heated, or changed for another.

(*c*) *The Tube Fluoresces.*—This is the desired state. A certain amount of judgment must now be exercised. With a 6-in. coil or less, the tension of the contact breaker may be adjusted until nearly the full power of the coil is used. With a larger one the power required may be best judged by examination with a screen. No object is to be gained by forcing a powerful current through a soft tube, as it merely becomes overheated without any great gain in penetration. Very low tubes should be kept for photographic work or screen examinations of such thin parts as the hand. For examining thicker parts with the screen a hard tube will be necessary.

Screen Examinations.—The fluorescence of even the best screen is invisible in broad daylight. Indeed, the utmost precaution should be taken to prevent any light from falling on either the screen or the eye of the operator whilst making an examination. The fluorescope, which was described on p. 132, shuts out the light very effectively, but as it is generally used in a light room it takes some time for the eyes of the operator to get accustomed to the darkness within. When examining a deep part, such as the thorax, with a fluorescope, a peculiar effect is produced, especially on a bright day. At first nothing is to be seen but the black shadow of the body. As the eyes get more and more accustomed to the darkness, details gradually develop like the details of a developing photographic plate. First, the shadow of the ribs become visible, then the outline of the heart, and so on.

For examining injuries of the extremities the fluorescope is very useful, but for deeper parts a dark-room is necessary. Indeed, all screen work, however simple, is best done in a dark-room. The fluorescope is rather a clumsy piece of apparatus, employing both hands, and even when fixed on a stand it is rather awkward to manipulate. On the other hand, a screen stretched on a light frame and mounted on a foot so that it can stand vertically, is much more handy.

The chief use of the fluorescope is to examine parts with a view to finding the best position in which to photograph them. This subject is discussed later on, so that it need only be mentioned here.

The amount of ordinary light given out by the fluorescing glass of an excited focus tube is only realised when seen in a dark-room. Some covering is necessary. In Roentgen's original experiment it was wrapped up in black paper, but for ordinary purposes a specially made box of thin ebonite, which will hold both tube and clip, is most useful.

Neither of these contrivances is necessary when one of the red tubes is used, as the red light is not only more feeble but it is much less dazzling in its quality than that given out by an ordinary tube. Another source of light which is sometimes annoying in a dark-room is the spark at the platinum contacts of the break.

Some workers keep the coil covered up. Others have a cardboard box fitting over the contact breaker. Others again have the coil in a separate room or behind a wooden screen. A mercury break being separate from the coil is easily covered up, but, as a rule, gives an annoying flicker on the screen. The mercury jet break fulfils every condition for use in the dark-room.

Even with a rapid rotating break there is a certain amount of flicker, but the intervals of light and darkness are so rapid that the eye retains the general impression of a fairly steady light. There are, however, circumstances under which the intermittent nature of the illumination becomes apparent. If a hand be examined in a dark-room, so long as the hand is at rest a seemingly steady shadow of the bones will be seen, and if the hand be slowly moved no change will be noticed, but if it be moved rapidly backwards and forwards behind the screen, instead of a moving shadow a series of shadows will show on the screen. The operator, whose eyes retain the impression of several of these, will see a most irritating series of overlapping shadows.

Localising Foreign Bodies with the Screen.—Such foreign bodies as needles, shot or bullets in the extremities may be readily recognised by a screen examination. This in itself is undoubtedly an advantage to the surgeon; but the shadow is often very misleading and difficult to interpret. A little experience, however, enables one to make a fair guess as to the position of the metallic substance. Take, for instance, one of the photographs on Plate IV., which shows two foreign bodies in a left forearm. As a matter of fact, both these radiograms were taken from an arm which did not contain any foreign body. Two square pieces of sheet lead were cemented to the arm, so that, as it lay on the plate, one piece was below the arm, touching the plate, and the other as far from the plate as the thickness of the arm would allow. The question to be answered is: What are the relative positions of the bones and the two pieces of lead? Imagine for a moment that the shadow seen on the screen was exactly similar to that seen in the right-hand photograph.

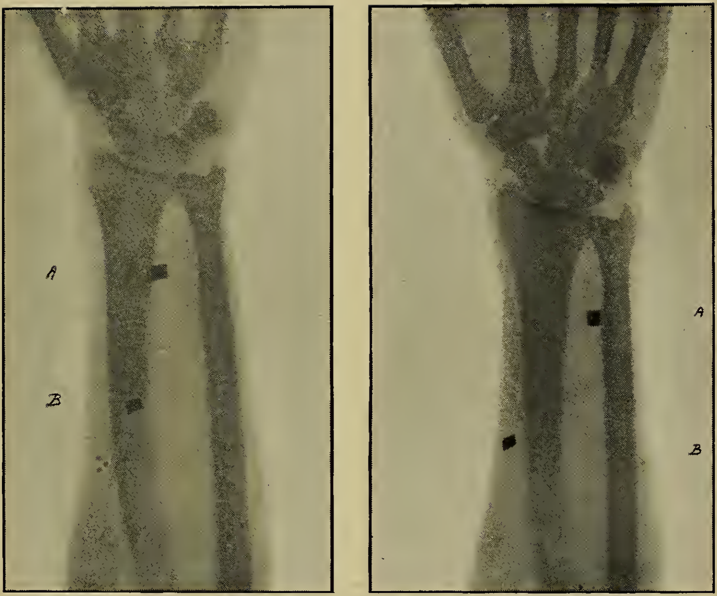


Plate IV.—A Method of Localisation.

Two things are at once evident: (*a*) that the piece of lead nearest to the carpus throws a larger shadow than the other. As they were equal in size, this indicates that the larger shadow is that of the piece farther from the screen; (*b*) that the larger shadow is not quite so well defined as the small one. This points to the same conclusion. The shadow of the piece farthest from the screen would throw the dimmer shadow.

Thus, without any further investigation, we gather that the piece A lies deeper than the piece B.

Next comes the question whether the pieces of lead are on the near or far side of the bone; the expressions near and far being used to indicate the side nearer or farther from the screen.

Keeping the tube and the screen stationary, the arm was moved through a distance of 7 or 8 ins. to the position shown on the left of the figure. The relative positions—the shadows of the bones and the two pieces of lead—have now entirely changed. The piece of lead, A, has apparently moved across from the ulna towards the radius, or *in the direction in which the arm has been travelling.* A moment's consideration will show that the shadow of the lead must, therefore, have travelled farther than that of the bone. The lead must, therefore, be nearer the source of illumination, *i.e.*, it must be *on the side of the arm remote from the screen.*

The shadow, B, gives the opposite effect, as the arm moves from right to left; the shadow of the lead travels back from outside the bones to the centre of the radius, that is, its position relative to the shadow of the bone has travelled in a different direction from that in which the arm has moved. Following the same reasoning as before, we conclude that the piece B is on the nearer side of the arm.

Such a method is not mathematically accurate, but when better means are lacking, and a rapid localisation is necessary, it is useful. Very little practice will enable any one to make a fair guess at the depth of a foreign body embedded in the thinner parts of a human body.

The Punctograph.—Although the above affords a simple method of approximate work, there are means of more exact procedure, without resorting to the photographic plate. The punctograph is a little instrument consisting essentially of a stout ring of brass attached to an ebonite lath. An aniline pencil is held by a spring in such a manner that, on the release of the spring, it runs through the brass ring and will mark anything against which the ring is pressed. For localising a foreign body, for instance a shot in the arm, two punctographs are used. The screen is set up on a stand so that both hands of the operator may be free. The arm is held up so as to cast a shadow of the shot on the screen, then one of the punctographs is placed between arm and screen so that the shadow of the ring has that of the shot in its centre. The other punctograph is then placed on the other side of the arm, and adjusted until the shadows of the rings overlap, that of the shot still forming their centre. On releasing the triggers each aniline pencil makes a dot on the arm. The shot will of course lie on a line drawn through the arm from one dot to the other. A slight practical difficulty comes in when the arm is so thick as to make one ring much closer to the tube than the other. The ring nearest the tube throws a much larger shadow on the screen than the other, so that the two do not overlap but form concentric circles around the shadow of the shot. The arm is next turned into a slightly different position, but still showing a shadow of the shot, and the operation is repeated.

Four dots will now be found on the arm, and a rough measurement and calculation will indicate the position of the shot. In the diagram (Fig. 48) a section of the arm is shown with the shot x, and four marks, a, b, c and d. On measurement a, b is found to be 7 millimetres, whilst c, d is 19. On measuring *a*, *d* with a pair of callipers, it is found to be 74 millimetres, whilst *b*, *c* is 76 millimetres. For practical purposes *x*, *a*, *b* and *x*, *c*, *d* may be considered similar triangles, so that the shot will be found between *b* and *c* at a distance of $\frac{bc \times ab}{ab + cd}$, or in the special case under consideration of $\frac{76 \times 7}{7 + 19} = 20{\cdot}4$, or say 20 millimetres.

Very good results may be obtained with these instruments if care be taken to keep the points of the pencils fairly sharp. These require a certain dexterity of manipulation, and may both be managed with one hand if necessary, but it is best to have the screen on a stand, and get an assistant to hold the patient's arm or leg in position, so that both hands may be free for the adjustment of the punctographs.

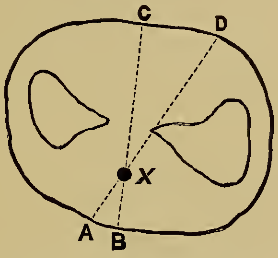


Fig. 48.—Punctograph Diagram.

Payne's Method.—In the above method of localisation the marks are made on the skin of the patient. This is to a certain extent an advantage, but it leads to slight inaccuracies in measurement from the fact that *a*, *b* (see Fig. 48) is not necessarily parallel to *c*, *d*, nor are *a*, *d* nor *c*, *d* straight lines. Mr. E. Payne's method is not subject to these drawbacks. The apparatus, which is merely a special form of stand for tube and screen, will readily be understood from the figure (49). The tube is held in a stand of the type suggested by Mr. Payne (see page 127). The two glass holders are fixed to a sliding block which runs in grooves, so that it can only move in a horizontal line parallel to the plane of the screen, S. In the figure three sets of grooves are shown, so that the horizontal line along which the tube moves may be adjusted at any one of three distances from the screen. A scale is fixed on top of each groove so that the block may be displaced accurately through any desired distance.

At the back of the screen are two leaden cross-wires, which may be covered with ink or aniline dye to mark the skin of the patient.

The first adjustment is to place the tube in such a position that the point of emission of X rays is directly behind the point where the wires cross. This is facilitated by using a strip of metal about 3 ins. long by 1 or 2 ins. broad, bent into a right angle. This is held behind the screen, so that the angle rests on the point where the wires cross, whilst the edges rest one along each wire. The screen is raised or lowered until the shadow of the horizontal portion becomes as thin as possible; then the tube is moved until the perpendicular portion forms a like shadow.

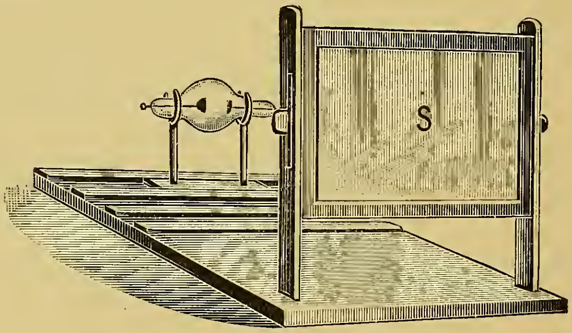


FIG. 49.—Payne's Localiser.

Having thus got the radiant spot of the anode perpendicularly behind the fixed point of the screen, the hand or arm or other part of the patient is placed between screen and tube. When the shadow of the foreign body—or, in the case of a needle, the shadow of one end—comes over the crossing of the wires, the part is brought up close to the screen to take the mark of the wires.

The tube is next moved a definite distance (say 6 ins.) along its groove. This will displace the shadow in the opposite direction, the shadow of the shot or needle point running along the horizontal wire. The distance of displacement is measured off with a pair of compasses and noted.

A simple calculation may now be made to find the distance from the surface to the shot or needle end. For the sake of rapidity a table may be drawn out, once for all, so that by reference to the measured distance on the screen, the depth of the foreign body may be read off in an adjacent column.

With a stand such as the one figured, four columns will be required for this table; one for the length, measured on the screen, and the other three recording the depth indicated by that measurement when the tube-stand is in either one of the three grooves.

Such a table is, of course, calculated out in the same manner as the calculation for a single operation. Mr. Payne describes the work as follows:—

"Let S S be the surface of the screen; A the first position of the tube, giving a shadow at D. Then, when the tube is at C, there is a shadow at F, and when at B, there is a shadow at E, O being the shot. Now, A D is known beforehand, as also A B and A C, and we measure D E and D F. The figure to show the distance of O from the screen may be prepared beforehand. We fill in the points E and F as observed, and by drawing lines B E, F C, obtain the position of O. If we employ threads and the apparatus recently devised by Mr. Mackenzie Davidson (see page 124), we adjust threads to represent the lines, and measure the distance of O from the table. A mark should also be made on the hand showing a point in a line with the shot when the tube is at A.

"For any fixed values of A B, A C and A D, we can work out a table giving the distance D O in terms of the observations D E, D F or E F.

"Since the opposite angles of O are equal, we have by similar triangles—

$$\frac{D\,O}{D\,E} = \frac{A\,O}{A\,C} \text{ or } \frac{A\,O}{A\,B},$$

$$\therefore D\,O \times A\,C = A\,O \times D\,E.$$

$$\text{Now, } D\,O = A\,D - D\,O,$$

$$\therefore D\,O \times A\,C = (A\,D - D\,O)\,D\,E;$$

$$\therefore D\,O \times A\,C + D\,O \times D\,E = A\,D \times D\,E.$$

$$D\,O\,(A\,C + D\,E) = A\,D \times D\,E.$$

$$D\,O = \frac{A\,D \times D\,E}{A\,C + D\,E}.$$

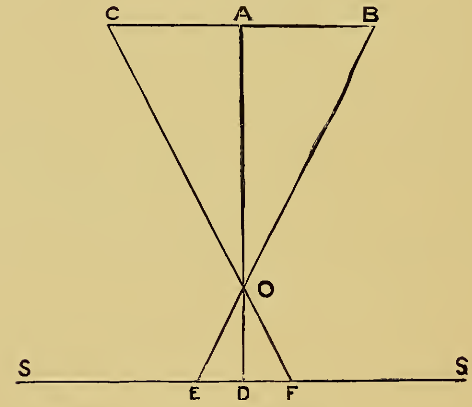


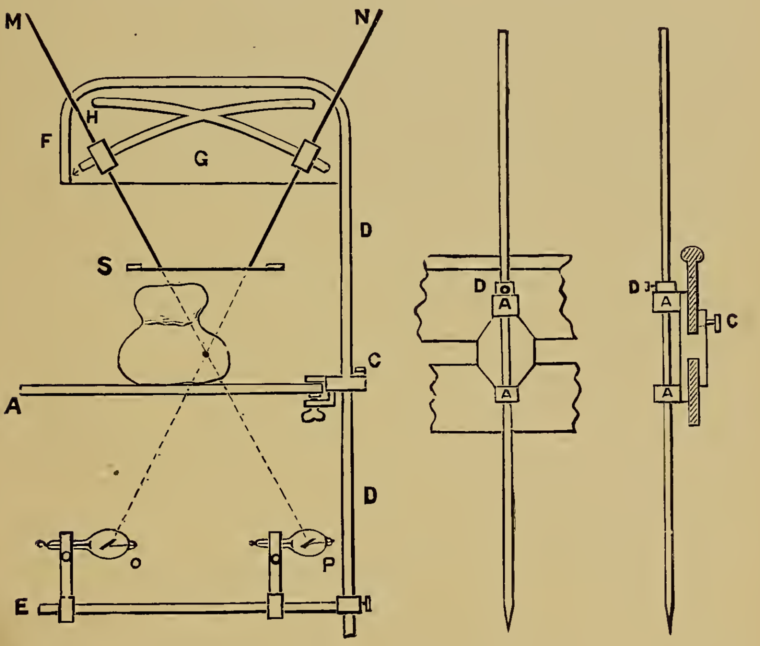
Fig. 50.—Diagram.

From this we can work out values of D O for different values of D E."

Dr. Rémy's Method.—Dr. Rémy, of Paris, has devised an apparatus which does away with all calculations as effectually as the cross-thread localiser, and has the additional advantage that it may be used with the screen or with plates. Its special usefulness is in screen work.

The apparatus, which is a localiser and tube-holder in one, is, at first sight, rather complicated. The Diagram I., Fig. 51, which only shows the essential parts, gives a general idea of its appearance. The lines A show a section across a table, to which the holder is clamped by a clip. D D is an upright rod about 3 ft. long, which can turn in the clip-block, C, but may be clamped in any position by a little screw.

The tube is held by a clip which may slide along the graduated rod, E.



I. II. III.

Fig. 51.—Rémy Localiser.

It will be noticed that the tube is thus directly under the table, and since the subject lies on the table, the examination is made from above. This is an instance of the chief difference between English and Continental methods. In England most screen examinations are made with the screen in a perpendicular plane, and with the rays coming more or less horizontally through the part under examination. On the Continent the tube is usually placed underneath the support on which the patient lies. With good transparent supports, such as a thin deal table, this method has many advantages. We shall return to this subject of the position of the patient when speaking of radiography.

The upper part of Rémy's upright rod D D is bent round, as shown in the figure, between the letters D and F, and within the curve so formed is fixed rigidly a strong sheet of brass, G. This sheet of brass and the graduated rod, E, are in one plane, and as the whole is rigidly connected so that the brass sheet and graduated rod, will rotate together when twisted around the clip-block, B. F will thus always be perpendicularly above E.

In the brass sheet, G, are cut two curved slots, H and K, which run across one another at their central points.

These slots are really portions of the circumferences of two circles. As the apparatus is arranged in the figure, the slot, H, is an arc of a circle whose centre is the anode of the focus tube, O. If the tube with its clip were slid along the rod, E, a certain fixed distance until it reaches P, the anode would become the centre of the arc, K.

For the sake of clearness, the actual localisers, named "materialised X rays" by Dr. Rémy, are drawn separately in II. and III. II. is a front and III. a side view of a steel needle, about 18 ins. long, fixed so that it may slide easily through two brass blocks, *a a*, which in their turn are fixed to a brass piece sliding in the slots (H and K in I.).

It will be apparent from I. that the needle, K, will always point along a radius of the circle, H, *i.e.*, towards the anode of the focus tube in the position shown, O. It will thus lie along the course of a ray or pencil of rays. Hence its name. In the same way the needle, M, will always point towards the focus tube in its second position, P.

When Dr. Rémy explained his apparatus to the London Roentgen Society, he experimented on a bullet inside a loaf of bread, as is roughly shown in the diagram.

His adjustments were as follows:—

(1) Turn the apparatus round in the clip-block until the focus tube swings out from under the table. Remove one of the needles, N, and glance through the holes thus left vacant (A A, Fig. 51, II.). Adjust the position of the focus tube, O, until the anode can be sighted through the two holes. Note this position. Repeat the operation with the holes for needle, N, to obtain the correct position, P.

(2) Swing the apparatus back so as to bring the tube under the loaf of bread. Return the needles to their positions; place the tube in the position, O. Hold a screen over the bread, excite the tube, and look for the shadow of the bullet. Lower N until its point touches this shadow. To do this the apparatus may require turning round a little in the clip-block. When the point of the needle touches the shadow of the bullet, clamp the screw, C, Fig. 51, I., and clip the needle tight by the screw, C, Fig. 51, II.

(3) Change the position of the tube to P, Fig. 51, I., and lower M until it touches the shadow in its new position. This will require no rotation of the apparatus. Clamp the needle in this position, and remove the screen. Both needles will now be pointing directly to the bullet. Lower each needle until it touches the loaf, and mark the two points of contact.

(4) Unscrew C, and swing the whole apparatus round so that the needles are no longer over the loaf. Now lower them until their points just meet, and screw the little stops, D, Fig. 51, II. close up to the eye-holes.

(5) Swing back over the loaf, drawing out the needles until they again touch the marked spots. The stops being fixed to the needles will now be at some distance from the upper eye, A, Fig. 51, II., and in each case this distance will represent the

depth of the bullet beneath the point touched by the needle in the direction of the needle's axis.

Dr. Rémy claims that this apparatus may be used in the operating theatre, but as operating theatres are not dark, nor are operating tables adapted to such apparatus, it will probably be found most useful in the radiographer's dark-room.

Plate V.—Stellate Fracture of Patella showing Shadow of "Strapping".

CHAPTER III.

RADIOGRAPHY.

Radiography, or the use of photographic methods, is much slower and less convenient than radioscopy, or the use of the screen. It has, however, certain advantages. The record given by a photographic plate is not only permanent but clearer, better defined and fuller of minute detail than that given by a screen. Further, the effect of the rays on a plate is cumulative, so that an image which when thrown on a screen is not perceptible can be registered on a plate by merely prolonging exposure. In this way radiograms can be made of such parts as the pelvic region of an adult which are beyond the reach of the screen.

Photographic Materials.—There are so many excellent text-books on photography that it would be a waste of time to enter here into all the details of development, fixing, intensifying and printing. There are, however, certain differences between radiography and photography, and it is to these which attention will be given in the following pages.

Dry Plates.—I have seen it stated in various places that the X rays have no effect on a wet plate. Whether this be so or not, wet plates are ill adapted for radiographic purposes.

In Roentgen's original paper, it was pointed out that either films or plates might be used indiscriminately. In par. 6 occurs the statement:—

"It is still open to question whether the chemical effect on the silver salts of photographic plates is exercised directly by the X rays. It is possible that this effect is due to the fluorescent light which, as mentioned above, may be generated on the glass plate, or perhaps in the layer of gelatine. Films may be used just as well as glass plates."

Since the time when this paper was published, X ray workers have tried well nigh every brand of film and plate on the market, whilst makers have experimented with special emulsions.

No very startling improvement has been made in the preparation of plates, and the general concensus of opinion seems to be that any good brand of very fast plate gives excellent results. At one time there were statements abroad that a slow plate was as rapid under X rays as a quick one, but this is a fallacy. I have used many brands, but have always found those which are fast for ordinary light are fast for X rays. Isochromatic plates I have always found very slow. This statement must be taken as merely relative and not quantitative. It may be that the plate speeds of widely differing brands are nearer together for X rays than for light, but I have come across no exact experiments on the subject.

Perhaps the favourite plates are the Cadet lightening, the Paget xxxxx, and the Lumière plates. I give personal preference to the Imperial flashlight plates. The best advice, however, to any one who wishes to take up radiography, and who is already a photographer, is to use those plates which he understands.

One of the difficulties in development is to obtain density. Radiograms are apt to be thin and lacking in contrast. To overcome this difficulty, and at the same time to decrease the time of exposure, special plates and films have been made coated on both sides. The rays after having done their work on the first coat pass on with very slight diminution and produce a fresh image in the second one; if the plate be thin there is no practical difference between these images which are of course in perfect register. Such plates are a little awkward to develop but give good results.

As it is not often necessary to print a large number of copies from any radiogram, some workers prefer to use X ray paper, which is a very rapid form of bromide paper. It has the advantage that several sheets of the paper may be placed one beneath the other, and all exposed to the action of the rays at the same time. Each piece offers scarcely any resistance to the rays, so that it is quite possible in this manner to expose a dozen together without suffering much loss in sharpness and detail. On development a negative effect of the shadow is shown, the bones appearing white against a dark background, but this does not in any way depreciate the value of the picture.

Large photographic plates and papers are rather costly, so that, as a matter of economy, it is as well to use the smallest plates that will give all the details required. They are made in two sets of sizes, Continental and English.

The table gives the English sizes in inches and Continental in centimetres. Those sizes, which are approximately the same, are placed in the same line, but in no case are they exactly alike. This should be remembered when ordering dark slides to fit certain sized plates. An asterisk marks the longer plate.

English.	Continental
a 4¼ × 3¼	12 × 9*
5 × 4	13 × 10*
b 6½ × 4¼*	15 × 11
6½ × 4¾*	16·5 × 12
7¼ × 4½*	18 × 13
7½ × 5	20 × 12*
c 8½ × 6½*	21 × 16
9 × 7	24 × 18*
10 × 8	26 × 21*
12 × 8*	27 × 21
13 × 8	
12 × 10*	30 × 24
15 × 12	40 × 30*

a Quarter plate.
b Half plate.
c Whole plate.

Larger sizes are not, as a rule, kept in stock, but may readily be obtained. They are generally made on much stronger glass than the sizes in the list.

Films have some advantages over plates. They are more portable and not liable to fracture; but, unless spread on a rigid, flat surface, they are apt to bend and complicate the distortion of shadows. The Austin-Edwards' snapshot films give good results.

A film which is used a good deal for X ray work is the "Cristoid," made by the Sandell Plate Co. It is simply a gelatine film without any mounting substance, and is made up of two emulsions, one very rapid and one medium. These films may be purchased ready packed in dark envelopes. They present considerable difficulties in development, and are much slower than fast plates. Their great advantage is that they may be used in the tropics, where films mounted on celluloid are useless.

Dark Slides.—To obtain a well-defined radiogram it is necessary that the subject to be radiographed should be as close as possible to the plate. Hence the thinnest covering should be used that will keep out the light. For most purposes light tight paper envelopes are convenient. These are made by Messrs. Tyler, and can be obtained from any photographic dealer. Or if desired, films may be purchased ready packed in the envelopes. As mentioned in the last paragraph, the Sandell Co. pack films in this way, but no doubt other makers would do so to order. The plate on its removal from the box is placed in an envelope of yellow paper, and this in its turn is placed in a stout black envelope. Some system is necessary in doing this or else the operator will be apt to forget which was the sensitive side of the plate. A plate exposed on the wrong side is very irritating, for although a good result may be obtained, the reversal of the image often leads to misunderstanding. The system usually adopted is to place the plate so that the sensitive surface is in contact with the seamless side of the yellow envelope. The yellow envelope may be then placed in the black one so that the seamless sides of the two envelopes come together.

It need hardly be said that all operations in which dry plates are handled, should be conducted in a dark-room.

A difficulty in using plates packed in envelopes is that they are apt to break when any weight is brought to bear on them, unless they are lying on a flat, rigid support. This leads many to prefer a special dark slide. It consists of a strong wooden back on which the plate lies, and a hinged cover. The cover is made of black cardboard, which has the various sizes of plates marked on its outer side by white lines. When small plates are used, wooden carriers are placed inside the slide to keep them central.

When an intensifying screen is used, it is very necessary that the screen shall be held closely in contact with the plate. Under these circumstances the envelopes will be found inconvenient, and a dark slide is practically indispensable.

Before leaving the subject of protecting plates from light, a few words should be said about protection from X rays. Of course, unexposed plates in their envelopes should not be brought near a working apparatus. In an hospital where several radiograms must be made consecutively at some distance from the dark-room, it is a decided convenience to have some means of carrying about unexposed plates. For this purpose I use a wooden case lined with lead, which will hold a dozen plates of any size up to 10 × 12 ins. with their envelopes. When the case is closed, the plates within are practically safe from fogging.

In some portable installations a special metal-lined compartment is provided for plates; but most workers will prefer, even when their plates are protected by a metallic covering, to place them at some little distance from the excited tube.

Arrangement of Apparatus.—The actual position of each part of the apparatus, when taking a radiogram, will vary according to the size and type of apparatus used, and the convenience of the operator. The simplest arrangement is to put the plate, in its envelope or dark slide, under the part to be examined, and arrange the stand so that the tube is held above the subject. This keeps both patient and plate steady, and is the position in which most radiograms are made in England;[1] but there are cases in which other positions are necessary, as, for instance, in the fractured patella (Plate V.). Here it was undesirable to move the patient, so the plate was placed vertically by the side of the knee, and held in position by sand bags, the focus tube being placed at the other side of the knee.

Distance from Tube to Plate.—In deciding the distance from the plate at which the tube must be placed, various circumstances must be taken into consideration, the chief of these being distortion, illumination and nature of subject.

Distortion.—If a candle be held at a distance of 18 ins. from a piece of white paper, and two halfpennies be held so as to cast a shadow on the paper, it will be at once seen that the size of the shadow of the one nearest the paper is smaller than that of the other. In the same way the radiographic shadow of an opaque object which is some distance from the plate will be larger than one close up.

Pursuing the shadow analogy, if one of the halfpennies be

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[1] It has already been pointed out (page 149) that the Continental method is to place the tube beneath the support on which the patient lies. This will necessitate some form of holder for the plate and its covering, which is thus fixed rigidly to the couch, and less liable to displacement by the patient. Another advantage of this system is that a screen examination may be made before taking the radiogram, and when the best position for viewing the part under consideration is found, the plate may be brought into position and exposed without moving the patient in any way. Further, plates are not liable to fracture, films are not bent, and either plates or films may be adjusted so as to give the least possible distortion.

held parallel to the paper so that the rays from the candle fall normally on its surface, the outline of the shadow will be a circle; but if it be held still parallel with the plane of the paper, but so that the rays fall obliquely, the shadow outline will become elliptical. This distortion will be less if the source of light is far off than if it is near. Thus the distortion will have the effect of giving incorrect ideas of sizes, distances and outlines. It will at once be seen that the farther the source of illumination is from the objects, the less will be the distortion. In the limit, when the illuminating point is at a practically infinite distance, as, for instance, in a shadow cast by the sun on a sheet of paper held perpendicularly to the direction of the rays, the shadow is without distortion, the rays having become practically parallel.

When taking a thin part (hand or arm), this limit is very soon reached. The distortion over a 10 × 8 plate with the tube at a distance of 18 ins. is very small. A glance at the two radiograms on Plate IV. will give a definite idea of *distortion.*

When films are used and get bent, an entirely new class of distortion is introduced, which need not be discussed here.

Illumination.—Roentgen found that the X rays whilst passing through air obeyed the law of inverse squares. In his first paper he states (par. 10):—

"I succeeded with a water photometer—I do not possess a better one—in comparing the intensity of the light of my fluorescing screen at a distance of about 100 mm. and 200 mm. from the discharge apparatus, and found in the case of three tests, agreeing well with one another, that it varied very nearly inversely as the square of the distance of the screen from the discharge apparatus. Hence the air absorbs a much smaller fraction of the X rays than of the cathode rays."

Thus, although the air absorbs little, the illumination dies out very rapidly as the distance is increased, which considerably lessens the possible distance.

In a catalogue of German apparatus issued in 1896 by a high-class firm, amongst the directions for taking radiograms occurs the advice: "The distance of 10 ins. should be considered as standard (from mirror to screen or photographic plate)".[1] If this distance be increased to 20 ins., using the same apparatus, the exposure required would be four times as great. Improvements in apparatus have, however, reduced exposures considerably since the time when the above statement was made.

Production of Secondary Rays.—A circumstance that places a limit on the time during which it is advisable to expose a plate, and hence to the distance between tube and plate, is that X rays, or perhaps, cathode rays, when passing through more or less opaque substances, are apt to produce other (secondary) rays, which, seeing that their point of origin is not at the anode of the tube, lead to blurring of the image. In short exposures they are negligible, but they always make themselves evident when exposures are very long.

Roentgen has investigated this peculiar phenomenon, and in his third communication to the Prussian Academy of Sciences, describes experiments on the subject as follows:—

"If we have a discharge apparatus emitting intense rays, and place between it and a fluorescent screen, an opaque plate in such a way that the screen is entirely in shadow, we shall still observe illumination of the barium platino-cyanide. The illumination is still visible when the screen is placed directly against the opaque plate, and one is at first disposed to think that the plate is transparent. If, however, the screen, lying against the plate, is covered with a thick sheet of glass, the fluorescent

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[1] Catalogue of Louis Müller-Unkel. This is the firm's own translation of Die Entfernung der photographischen Platter oder des Phosphorescenz-Schirms, von dem Platin-reflector, sollte stets ca. 25 cm. betragen.

Plate VI.—Sarcoma.

light becomes much weaker, and disappears entirely if, instead of the glass, we surround the screen with a cylinder of lead 1 cm. thick, which is closed at one end by the opaque plate, and at the other by the head of the observer.

"The effect just described might be due to the deflection of rays of very long wave lengths, or to X rays emitted by bodies in the field of the discharge apparatus, such as the air.

"The latter explanation is the correct one, as may be readily shown by the apparatus about to be described. The figure (52) represents a thick bell glass, 20 cm. high and 10 cm. wide, closed by a thick zinc plate cemented to it. At 1 and 2 are fixed segments of sheet lead slightly larger than half the sectional area of the bell; X rays which enter the bell through the aperture in the zinc plate, covered with celluloid, are prevented from reaching, in a direct manner, the space above segment 2. On the upper side of this lead sheet is fixed a barium platino-cyanide screen, which almost fills up the entire area of the bell. The screen can neither be struck directly nor by rays which have undergone a single diffuse reflection from any hard substance (the glass walls, for example). Before each experiment the bell is filled with air free from dust. If X rays are allowed to enter the bell, and in such a manner that they are intercepted by the lead plate 1, no fluorescence is observed on 2; only when, after tilting the bell, direct rays

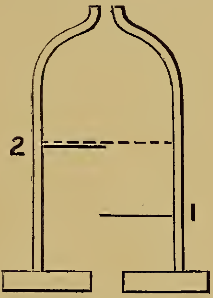

FIG. 52.—Roentgen's Experiment.

reach the space between 1 and 2 does the screen light up on the half not covered by the lead plate 2. If the bell is connected up to an aquatic air-pump, the fluorescence will be observed to diminish as the exhaustion proceeds; if air be admitted, the fluorescence again increases.

"Since then, as I found it, the simple contact with air on which the rays have just fallen, does not give rise to any noticeable fluorescence of the barium platino-cyanide, we conclude, from the experiment just described, that the air, when struck by the rays, sends forth rays in all directions.

"If our eyes were as sensitive to X rays as they are to light rays, a discharge tube would appear to us like a light burning in a room uniformly filled with tobacco smoke; perhaps the colour of the direct rays would differ from those coming from the particles of air.

"The question whether the rays emitted by the objects struck by the rays are the same as the direct ones, or, in other words, whether a diffuse reflection or an action resembling fluorescence is the cause of these rays, I have not as yet been able to decide. It can easily be shown that the rays emitted by the air are capable of photographic effects, and their effect often shows itself in a manner unwished for by the observer. *To guard against this, which is often the necessary accompaniment of long exposures, we must protect the photographic plate with a suitable lead screen.*"

Nature of Subject.—It is evident that when a hand is to be radiographed, the tube can be brought fairly near without very great distortion; but in radiographing the thorax of an adult, there must be room for the depth of the chest between plate and tube, and unless the tube be removed to a considerable distance the distortion will be very great.

From consideration of all these circumstances, it will be seen that no fixed distance can be stated as absolutely the best. Dr. Chisholm Williams stated in a paper read before the

Roentgen Society at the beginning of last year (1900), that he considered any radiogram practically useless which was made with less distance between plate and screen than 18 ins. Most workers seem to prefer from 12 to 24 ins., but each case must be decided on its own merits.

Preparing the Tube for Making an Exposure. — The influence of heat on the penetrating power of a tube has already been discussed. Whether a tube should be used hot or cold is a subject concerning which even the ablest operators disagree. Mr. A. W. Isenthal, who generally uses the Volt-ohm double bulb tube, never heats it, whilst Mr. Wilson Noble, an ex-president of the Roentgen Society of London, considers that a hard tube which has been softened by heating is more efficient than a cold one which has been exhausted so as to be soft at the ordinary temperature of the air.

He says: "I believe that the principal benefit derived is that the heat promotes activity amongst the molecules, and it is this activity which enables a current to pass and form cathode rays, the *fons et origo* of Roentgen rays.

"I have come to this conclusion from the fact that if you have two tubes working with a spark gap of, say, 3 ins., one of which has been warmed down to this resistance, while the other works at it normally, you will get a far better result with the former tube than with the latter, though the vacuum and resistance may, I presume, be considered the same. If this is correct, it would seem that anything that will produce activity among the molecules, other conditions being equal, is an advantage to the tube."[1]

In any case, heating has this advantage: that tubes which have gone hard by continual use can be used hot long after their resistance has become too great for the coil ordinarily used by the worker.

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[1] *Archives of the Roentgen Ray*, vol. ii., 74.

The simplest method is to use a spirit lamp. The tube is turned backwards and forwards over the flame until it feels fairly hot, then attached to the stand connected with the coil, and the exposure made. This, however, is somewhat clumsy, and usually the tube cools down during the exposure.

An improvement on this method is to heat the tube constantly during exposure. Naturally, no heating apparatus can be interposed between the tube and the object to be radiographed, but it is possible to apply heat to that part of the tube behind the cathode. Mr. W. Webster advises the use of a spirit lamp with an insulating handle. He gives the following practical hints on heating tubes:—

"The tubes I obtain from Messrs. Newton are always in good condition, but for my purposes I still further condition them by alternate heating and cooling. . . . Heating the tube during working saves the platinums of 'make and break' of the coil. It has happened on several occasions that tubes would not condition for days. I therefore put them by for a rest of two or three months, and to my surprise they proved to be in good condition when tested. By the term 'condition' I mean that the tube works with an almost straw-coloured anode, with a white nucleus at the point of bombardment of cathode rays, even to a spheroidal condition, due to electrical molecular tension on the surface of the anode, without any blue or magenta-violet phosphorescence behind the anode. . . . In heating the tube, care should be taken not to allow the flame to play upon the bulb, but behind the cathode. As the tube approaches the desired condition, it will be noticed that the rapping of the make and break becomes rapidly modified, sometimes producing a musical note. This is specially the case when using a 10-in. coil."

Instead of the spirit lamp, an Argand burner may be used; but, as a rule, this will not be found so convenient, the gas supply-tube being rather a nuisance.

Exposure.—In radiography, as in photography, the greatest difficulty to be overcome by the beginner is to determine the time of exposure which will give the best results. So many factors enter into the determination of this exposure time, that it is quite impossible to give any definite rule. Dr. Mackintyre has taken radiograms of a frog's leg so rapidly as to produce cinematograph effects, whilst Prof. Roentgen has radiographed the bullets inside a loaded rifle in twelve minutes, and exposures of half an hour have often been given in radiographing a hip.

The chief factors to be considered are:—

Nature of the subject.
Size and efficiency of the coil.
Current used in the primary coil.
Distance of the tube.
Resistance and general character of the tube.

These, again, are, to a certain extent, interdependent, as the operator will select his tube, arrange the distance between tube and plate, and determine the electrical conditions according to the subject.

Nature of the Subject.—The question is often asked: What is transparent and what is opaque to the X rays? Of course there is no definite answer to this question, any more than there is to the same question when asked with regard to light. Just as thin sheets of gold, silver or platinum are transparent to light, and have had such physical constants as their indices of refraction determined, so no known substance is opaque to X rays. It is, therefore, merely a question of degree. And one of the difficulties of the radiographer is to arrange his exposures so as to differentiate between different substances, all penetrable, but in varying degrees.

No doubt some easily ascertainable physical or chemical quantity will eventually be discovered which determines the transparency of a substance, but at present no connection has been definitely formed between X ray transparency and the other properties of a body.

Roentgen, without describing any accurate measurement gave a list of substances with which he had experimented, and also stated his first idea as to the property which seemed to be most intimately connected with opacity, namely, density.

In par. 2 of his first paper he said :—

" Paper is transparent, the fluorescent screen still lighted up brightly when held behind a bound volume of 1,000 pages; the printer's ink offered no perceptible obstacle. Fluorescence was also noted behind two packs of cards; a few cards held between tube and screen made no perceptible difference. A single sheet of tinfoil is scarcely noticeable; only after several layers have been laid on top of each other is a shadow clearly visible on the screen. Thick blocks of wood are also transparent; fir planks from 2 cm. to 3 cm. thick are but slightly opaque. A film of aluminum about 15 cm. thick weakens the effect considerably, though it does not entirely destroy the fluorescence. Several centimetres of vulcanised rubber let the rays through. Glass plates of the same thickness behave in a different way, according as they contain lead (flint glass) or not; the former are much less transparent than the latter. If the hand be held between the tube and the screen, the dark shadow of the bones is visible within the slight dark shadow of the hand. Water, bisulphide of carbon, and various other liquids behave in this respect as though they were transparent. I was not able to determine whether water was more transparent than air. Behind plates of copper, silver, lead, gold, platinum, fluorescence is still clearly visible, but only when the plates are not too thick. Platinum 0·2 mm. thick is transparent; silver and copper sheets may be decidedly thicker. Lead 1·5 mm. is practically opaque, and was, on this account, often made use of. A wooden rod of 20 by 20 mm., cross section, painted with white-lead paint on one side, behaves in a peculiar manner. When it is interposed between apparatus and screen, it has almost no effect when the X rays go through the rod parallel to the painted side, but it throws a dark shadow if the rays have to traverse the paint. Very similar to the metals themselves are their salts, whether solid or in solution."

In par. 3 he continues:—

"These and other experimental results led to the conclusion that the transparency of different substances of the same thickness is mainly conditioned by their density. No other property is in the least comparable with this. The following experiments, however, show that density is not altogether alone in its influence. I experimented on the transparency of nearly the same thickness of glass, aluminium, calcspar and quartz. The density of these substances is nearly the same, and yet it was quite evident that the spar was decidedly less transparent than the other bodies, which were very much like each other in their behaviour."

Many experimenters have since then made comparative trials, both radiographic and radioscopic, with many substances, and this relationship between density and opacity has been borne out to a certain extent, though exceptions, such as that of calcspar in the above quotation, have been frequently noted.

If we turn to the chemical composition, we find that molecular weight has no relationship with opacity, or else the proteid matter of flesh would be infinitely more opaque than bone; but the atomic weights of the elements contained in each substance would seem to be very closely related to opacity.

Take, for instance, the substances experimented upon by Roentgen, omitting for the moment glass, whose composition he does not state. We have as atomic weights:—

Aluminium	27		
Calcspar ($CaCO_3$)	Calcium 40	Carbon 12	Oxygen 16
Quartz (SiO_2)	Silicon 28		Oxygen 16

If the heaviest element should have a preponderating influence on the opacity of a body, then we should expect aluminium and quartz to have much the same opacity (27 and 28), whilst calcspar (40) would be far more opaque than either, which is exactly the case.

Glass is so variable in composition that it cannot be readily included in the list, but it is stated (p. 166) that a little lead will make it very opaque, which, seeing that the atomic weight of lead is 206½, would bear out the connection.[1]

The influence of the atomic weight of the heaviest element in a body is further carried out by Roentgen's statement already quoted, that "very similar to the metals themselves are their salts, whether solid or in solution".

Dr. Swain's experiments on calculi give further evidence on this matter. He found that their opacity did not vary with their density, as is shown in the following table:—

Specific gravity.	Opacity.
Oxalate of lime.	Oxalate of lime.
Uric acid.	Phosphatic.
Phosphatic	Uric acid.
Biliary.	Biliary.

The atomic weights of the chief elementary constituents may be placed thus:—

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[1] This variation in the composition of glass, and its corresponding variation in transparency to X rays, is so great that I may note one or two cases which have come under my notice.

Amongst the out-patients of St. George's Hospital, I have been asked to radiograph some seven or eight cases where pieces of broken beer bottles were supposed to be in the hand or arm, but in no single case was I successful.

Some years ago I crushed a test tube in my hand, and left several pieces in my thumb. Three of these have worked their way out at intervals, but one still remains, and can be distinctly felt. I have never been able to see it either on the screen or in a radiogram.

On the other hand, two cases, which I radiographed for the Out-Patient Department at St. George's Hospital, showed pieces of glass, which were afterwards extracted. One was that of a boy who had run a pipette into his hand and broken it, and the other was a woman, who had broken a piece of plate glass (window).

Plate VII.—Six-weeks'-old Injury to Elbow showing New Growth of Bone

Oxalate of lime - Calcium, 40; carbon, 12; oxygen, 16.
Phosphatic - Calcium, 40; phosphorus, 31; oxygen, 16.
Uric acid - - Oxygen, 16; nitrogen, 14; carbon, 12; hydrogen, 1.
Biliary - - Oxygen, 16; nitrogen, 14; carbon, 12; hydrogen, 1.

Whatever relationship may be eventually discovered between the opacity and other properties of a body, we may, for the present, take the two mentioned above as an approximate guide. In surgical work there is not much variety of substance to be dealt with, so far as opacity is concerned.

Bone is the most opaque substance in the human body, and the depth of the bone shadow shown on a plate, other conditions being equal, will depend on the quantity of bone which has come between the source of rays and the plate. Thus cancellous tissue will not give as deep a shadow as compact bone. This is difficult to show by means of process blocks, but can readily be seen by examining a good print of the skiagram of a shoulder, or, better still, a pair of stereoscopic prints, when the difference between the shadows, thrown by the shaft and the head of the humerus, will be at once noticed. It is also shown in the radiogram of a sarcoma shown in Plate VI.

Next to bone comes callus. Its transparency seems to depend on the quantity of salts which it contains. Newly formed bone is often so transparent as to be indistinguishable from the surrounding tissue. Intermediate stages may be seen in Plate VII., showing a six-weeks'-old injury, and Plate VIII., which shows an injury some years old.

The soft parts of the body also vary considerably in opacity, which seems to depend on three conditions—density, saline contents, blood contents.

Blood is comparatively opaque. An examination of Plate IX. shows a distinct heart shadow.

The lungs are particularly transparent, because of the small amount of tissue compared to their thickness. The liver and stomach, on the other hand, are very opaque—so opaque, in fact, as to render it almost impossible to find such semi-transparent objects as biliary concretions, gall-stones, or stercoliths by means of the X rays.

The opacity of the abdomen is increased by the contents of the intestines, so that skiagrams of the lumbar vertebræ or of the bones of the pelvis are always lacking in contrast, though sufficiently good results may be obtained to be helpful to the surgeon, as in the congenital dislocation shown in the frontispiece. Muscles are more opaque when tense than when relaxed. Plethoric patients are more opaque, and therefore require longer exposures than anæmic ones. In like manner, males require longer exposures than females.

A peculiar effect was mentioned by Major Beevor at a discussion on "The Radiography of Soft Tissues," by the London Roentgen Society. The account of his speech is taken from the *Archives of the Roentgen Ray*, vol. iii., p. 99:—

"Major Beevor, R.A.M.C., said, with reference to some cases in the recent Frontier War in India, that when a man had been undergoing great exertion, and was brought in wounded and perspiring, the penetration of the rays was very much delayed. He recollected two cases where men were wounded in the thigh, one by a fragment of telegraph wire and the other by a soft bullet. The muscles seemed to be so opaque to the rays that it was difficult to obtain any radiograph at the time. The man wounded by the fragment of telegraph wire had had a hard hand-to-hand fight with the enemy, and in this case he was not able to localise the piece of wire immediately, even when using a 10-in. spark. A day or two afterwards a radiograph was obtained, showing a fracture of the femur, and a large splinter of bone torn from one side."

It need hardly be said that thick parts need longer exposures as a rule than thin ones. Vandeveyer states that the necessary exposures for bodies or limbs vary about as

Plate VIII.—Old Fracture of Tibia and Fibula Badly Set.

the cube of the thickness, other conditions being equal. Other observers have given different formulæ for calculating the exposure, some even going so far as to suggest the making of a few trial exposures on some thin part, such as the hand, and using the time which gives the best result as a factor from which to work out the necessary exposure for any other part of the body.

Formulæ are, however, of very little use as yet, and no English workers seem to employ them. Each case is judged on its merits, giving long exposures to muscular or plethoric patients, and short ones to delicate or anæmic subjects.

As a radiographer is often called upon to make a radiogram of some injury where it is undesirable to remove the dressing or splints, a word or two about the different substances and tissues used in dressings is necessary.

The wood of a splint should offer no difficulties; its only effect is to remove the injured part to a certain extent from the plate, and hence to slightly blur the image; but, as a rule, it casts no confusing shadow of its own. Plate X., however, shows a curious effect caused by the wood and iron of a hinged splint.

A silicate does not offer great resistance to the rays, so that a radiogram may readily be taken of an injury which is put up in this manner.

Ordinary plaster or strapping is very annoying and opaque. Plate V., of a fractured patella, shows the effect produced by this substance, which, it must be remembered, contains lead.

Small quantities of boracic acid do not greatly interfere with the rays, but iodoform is very opaque. Even iodoform gauze has a definite effect on the shadow. Mercurial preparations, such as cyanide gauze, are also somewhat opaque.

Finally, the operator must, of course, expect to find shadows of pins on his plate.

Size and Efficiency of the Coil.—After having purchased an installation, this factor, in determining exposure, will remain a fixed quantity, so that the best way of expressing the electrical conditions is either by the length of spark used or by the ampèrage and voltage of the current passing through the primary coil. The latter needs no comment, as it is readily measured by suitable instruments—ammeter and voltmeter—but the spark needs some little attention.

Discharge rods of a coil are made in various forms. In most cases they terminate with points, whilst in some cases one carries a sharp point, whilst the other carries a disc or a ball.

In the Apps and Apps-Newton coils, both rods bear points, but the heads of the pillars which support the rods are spherical pieces of brass.

The spark passes most easily when the positive terminal is a point and the negative a disc or sphere. An instructive experiment may be performed with an Apps coil, bearing out this dependence of the length of spark on the shape of the terminals between which it passes.

Slide in the right-hand discharge rod as far as it will go, and turn it round so that the rod lies at right angles to the line joining the two pillars. Next, adjust the left-hand rod so that the distance between its point and the spherical head of the right-hand pillar is about half the nominal spark-length of the coil. Turn the commutator handle outwards so as to make the point the positive pole, and screw up the tension until a spark passes readily.

On reversing the current by means of the commutator, it will be found that no spark will pass, and the tension will have to be very greatly increased before any spark is seen.

Unfortunately, in X ray literature spark lengths are often written down without any information as to the shape of the terminals between which a spark passes. In a paper read before the Roentgen Society in March of this year, on the absorbability of various rays, Mr. Gardner explained that he used spherical ends to both his discharge rods when measuring the spark.

To make the spark length a reliable measurement, it would be necessary not only to state the exact shape and size of the terminals, but also the condition of the air through which the spark passed, such as temperature, pressure and humidity.

Again, sparks vary considerably in appearance. The spark from a good coil passes with a sharp snap, which is supposed to denote perfect insulation within the coil; such a spark is much more effective radiographically than a less snappy one. For screen work, a steady discharge is necessary; but for radiography *full* sparks at short intervals are more effective.

By full or fat sparks is meant sparks caused by comparatively large quantities of electricity. To illustrate the different forms of spark, any good coil may be used. First, it should be adjusted so that the maximum length of spark is obtained. The current is turned off, and the discharge rods arranged so that the spark gap is only half what it was before. Without altering the tensions, the current is turned on again. It will be seen that the spark is now thick, or rather, the spark itself is much as before, but surrounded by a glow which gives it the appearance of being one or two millimetres in diameter.

If the current be now turned off, and the rods brought so that their points are only ½ in. apart, and then, still without altering the tensions, the current be re-established, the snappy nature of the spark will have vanished, and the central spark will be surrounded by a thick glow, which is in reality a flame. This may be shown by blowing gently down upon it. The flame will then separate itself from the spark and form an irregular wavering arch across the terminals.

At the high temperature of the spark, the nitrogen of the air combines with oxygen, forming the flame, and producing quantities of oxides of nitrogen. This probably accounts partly for the smell given off under such conditions, and which is often put down entirely to ozone.

A piece of paper held in this flame will quickly catch fire.

Sparks thus vary in many ways, so that all tables of exposures in which the spark length is given without any further explanation, must only be accepted tentatively. A few failures must be expected at first, but acquaintance with a coil will soon enable an operator to use it to the best advantage in certain easy cases, and tables of exposures will then enable him to form an idea of what may be done in other cases.

Current Used in the Primary Coil.—The two measuring instruments usually attached to the circuit (ammeter and voltmeter) have already been described (page 39). The voltmeter may be practically ignored as a help to judging exposures. Its special use is to record the state of the batteries. The ammeter is by some used as the principal gauge by which to judge. Perhaps it would be more accurate to say that it is used to regulate exposures. If the electrical conditions under which an exposure is made can be repeated at will, then the only cause of variation in time will be the nature of the subject, and the ammeter is the best means of ensuring this accurate repetition.

Condition of the Tube.—In the chapter on "Tubes" it was stated that there is considerable discrepancy between the action of different kinds of rays on a fluorescent screen and their action on a photographic plate, a hard tube not acting on the plate so rapidly as a softer one.

The easiest kind of tube to take radiograms with is always the softest that will readily penetrate the part under examination, as scarcely any rays will penetrate the bones, therefore,

Plate IX.—Heart Shadow.

a fairly sharp negative may be produced with great latitude of exposure.

Nevertheless, expert workers generally use much harder tubes, and yet get very beautiful results.

If a hand be examined with a soft tube and a screen, a good black shadow is seen of the bones, strongly contrasted with the faint shadow of the flesh. A hard tube will give a poor, faint shadow of the bones, with a very flat appearance, though the whole screen will fluoresce more brightly than it did under the rays from the soft tube.

If the plate behaved similarly to the screen, it would be impossible to produce a good black and white negative with the hard tube, but, as a matter of fact, an accurate exposure with the hard tube gives a picture, not only as sharp as that given by the soft tube, but much fuller of detail. Moreover, the exposure required will have been much less.

To explain this action, we must refer to some of Roentgen's later work, in which he found that the more opaque class of substances not only stopped a large part of the rays falling on them, but also exercised a selective action, stopping the more photographically active rays more readily than those which have less activity.

Thus the rays starting from a fairly active tube are of various degrees of penetrative power and of photographic activity. On striking a hand they all pass through the flesh with little diminution, but as the penetrative ones pass through the bone the photographic ones are absorbed.

A screen would show the effect of the great penetration, and give a weak, flat shadow. The plate, on the other hand, is instantly acted upon by the intensity of the rays passing merely through air or flesh, but it will be some time before the cumulative action of the rays, which have lost so much of their photographic activity in the bone, will act on the plate.

An ideal exposure with a hard tube will act on all those parts of the plate exposed to direct rays, or rays that have merely passed through the flesh, and will just have begun to act on those parts which have received the rays filtered through bone. In this way both outline and structural details of the bone are shown.

The effect of using a hard tube is then to lessen the time of exposure, and at the same time to reduce latitude, so that although the best kind of work may be done by their help, they are the most difficult to manage.

When using a soft tube to photograph parts which it is able to penetrate, comparative long exposures are necessary, but much more latitude is allowable, and fewer plates will be spoiled.

In selecting a tube, it is best to try each one for yourself on a coil; as the alternative spark gaps marked on the outside of the tube are usually wrong. Indeed, they are so likely to vary whilst in stock that it is quite impossible for the dealer to say, without a definite trial, what the resistance of a tube may be.

General Suggestions for Exposures.—From all that has been said so far concerning the conditions governing exposures, it will be seen that no definite rules can be laid down; but if a beginner start with the times suggested below, he will soon become sufficiently expert to judge exposures for himself.

To photograph a hand on a very rapid plate, the following exposures have been recorded :—

With a 20-in. coil and a mercury break, one flash (one make and break) will give the outline of the bones; 20 flashes will give an excellent radiogram.

I have taken skiagrams of hands with a small coil only giving a 4-in. spark, and although they received 5 minutes exposure with the tube at a distance of 14 ins., they were distinctly underexposed.

The hand in Plate I. was taken with an Apps 10-in. coil,

Plate X.—Fractured Femur showing Grain of Splint.

working at about 7-in. spark, the tube being at a distance of 18 ins. from the plate, and exposure lasted 40 seconds.

Generally speaking, with the coils mostly in use, that is, 6-in. to 10-in., exposures of from 20 seconds to a minute, according to circumstances, may be used.

An arm requires from 1 minute in a child to 4 minutes in an average-sized man, and a leg, below the knee, will require about the same.

The thorax of a child may be taken in 2 minutes, and that of an adult in 4 or 5. The thorax shown on Plate IX. was of a child three years old, and took 1 minute.

The upper part of the leg will require from 2 minutes in a child to 5 or 6 in a man. The head and neck will require about the same. The abdomen and pelvis are the most difficult of all to radiograph, and all sorts of exposures, varying from 4 to 30 minutes, have been recommended.

Excellent work has been done with a 6-in. coil at a distance of 15 ins. in 10 minutes.

The radiogram of a congenital dislocation (Frontispiece) received an exposure of 2½ minutes, using a 12-in. spark.

Dr. Lewis Jones gives the following advice as to exposures with a 12-in. coil:—

"For the hand and wrist, 15 to 30 seconds; forearm, upper-arm and elbow, 1 or 2 minutes; shoulder and thorax, 3 to 5 minutes; knee and thigh, the same; pelvis and abdomen, up to 6 minutes. . . . The larger the coil the quicker may be the exposure, but, in addition, the sharper would be the picture."

A beginner will get the best results by using a comparatively soft tube and giving longer exposures, as in this way a fairly good result may be relied on, excepting in the case of the thicker parts of the body. When the use of soft tubes is mastered, harder ones should be tried. Rather more difficulty will be found in hitting the correct exposure, but facility will come with practice, and more detailed results will be obtained than was possible with the tubes of lower penetration.

Expert photographers often say that radiographers over-expose most of their plates. This may be so, but it is better to slightly over- than to under-expose. On development an over-exposed plate is apt to be thin and flat, with no contrasts, but it is not useless. An under-exposed plate will often give good contrasts, but the density is quite in the wrong place. Those parts of the plate which have not been covered by the subject will gain in density as development proceeds, but the bones will not appear at all, and the result will be merely a shadow of the limb, such as would be shown by a candle, and will be of no value whatsoever.

Position of the Patient.—There was a suggestion some time ago that a committee of the London Roentgen Society should draw up a set of directions as to the best position for taking various parts of the human subject. If this were done, and the instructions carefully adhered to in all cases, skiagrams would be strictly comparable one with the other. Surgeons would soon become accustomed to the point of view which would enable them readily to diagnose injuries or recognise a correct position.

However, as Mr. Davidson has pointed out, special positions are quite unnecessary when making stereoscopic skiagrams. No matter how great the distortion may be on each single print, a glance at the pair, arranged in a Wheatstone's stereoscope, will at once reveal the relation between the different parts. Indeed, injuries to complicated joints, as the elbow, shoulder, hip and ankle, can in many cases only be fully revealed by stereoscopic radiography.

In the absence, however, of either a hard and fast universal method, or a complete stereoscopic apparatus, the best rule that can be given is to always, if possible, make a screen examination; this will find the best relative positions in which to place plate, patient and tube.

When radiograms of the body are to be taken, the movements caused by breathing are apt to give confused shadows on the plate. A patient lying on his front generally gives clearer pictures than one lying on his back.

A method, which has been used to radiograph patients for renal calculi, is to lay the patient on his back, instruct him to take a deep breath, then turn on the current. When the patient has held his breath as long as possible, he must make a signal with his hand, the current is then turned off. He breathes once or twice, then inflates his lungs again, and a further exposure is made. Thus the whole of the exposure is made in the same phase of the respiration.

An automatic apparatus is sometimes used, which consists of a lever, one end of which is fixed to the front of the patient's chest, whilst the other end is connected with a mercury switch. Each time the lungs are inflated contact is made, and the coil works. At expiration the coil is not working.

Development.—Radiograms taken with a very small coil, and a soft tube, present very little difficulty in development, but those taken with a hard tube do not readily give good density. That is to say, the negatives prepared from plates exposed to a powerful apparatus are apt to be thin and lacking in contrast. In development, therefore, considerable care must be taken to counteract these difficulties as far as possible.

One of the chief differences between the various brands, and even between different batches of the same brand of plates, consists in the hardness or softness of the emulsion with which they are coated. A soft emulsion, when placed in the developer, swells up rapidly, and quickly becomes saturated with the developer. A hard emulsion is difficult to saturate, as the gelatine is slow in swelling. The consequence is that the developer only acts on the surface of a hard emulsion, and brings out the thinnest kind of image.

In ordinary photography, as is well known, there are circumstances under which the tendency is to produce a negative of greater density than is desirable, in which case hardness in the film is not so objectionable ; but in the main a soft emulsion is best. For X ray work it is a necessity.

The best method for ensuring density is to soak the plate well in water before pouring on the developer.

Having chosen a dish of suitable size, and mixed the requisite quantity of developer, the dish is filled nearly full of water, and the plate gently immersed. The dish is then rocked rather violently, holding it the while over a sink. This will detach all air bubbles from the surface of the plate. Some workers prefer to keep a wide soft brush to sweep over the surface of the plate while under water.

When it is seen to be quite free from adhering air bubbles, the dish is covered up with a piece of card, and left for one or two minutes, by the end of which time the film will have begun to soften.

The water is now poured off, and the developer poured over the plate with an even sweep. Considerable dexterity is required to do this with a large plate. Seeing the great value of the plate in comparison with that of the developer, it is best always to use plenty of the latter.

The image will now gradually appear, and development must be continued until of sufficient density.

Only experience will enable the radiographer to judge when development has proceeded sufficiently; moreover, the superficial appearance of the plate will vary according to the kind of developer which is used.

Usually every box of plates contains instructions both for making up the developer and for development ; and the best results with those particular plates will be obtained by using the developer recommended. Often a few words are appended to the development formula mentioning its peculiarities. Thus it is said of a developer which is very fashionable at present, *viz.*, metol and hydroquinone, that "the details will soon appear, and will rapidly gain in density". This hint should be acted upon. The details will appear, and the inexperienced operator will be tempted to remove the plate. It should be left to gather density which, in most plates, can be seen by looking at the back. As soon as the details are visible at the back of the plate, the density will be sufficient.

Pyrogallic acid developers do not bring up the details so rapidly, but give a full density by the time that the details are fully out. There is a considerable prejudice against this class of developer on account of the way it stains both fingers and plate. The fact nevertheless remains that nothing else gives quite such good results.

Another circumstance which affects density is the relative proportions of the different parts of the developer.

All alkaline developers consist of three parts:—

(*a*) A reducing agent—pyrogallic acid, hydroquinone, metol, glycine, etc. This actually does the work of blackening the plate, or reducing the silver bromide to finely divided silver. Its quantity may be varied almost to any extent so long as there is sufficient in the solution.

(*b*) A hastener—sodium or potassium carbonate or ammonia. The more of this and the more rapid will be the development. The quantity given in the instructions enclosed in the box of plates should be very closely followed.

(*c*) A restrainer—an alkaline bromide, which slows down the rate of development.

Good density may be obtained by using (*a*) lavishly, and developing slowly, either by using smaller quantities of (*b*) or increasing the quantity of (*c*).

Many expert workers object to restrainers, and only use them in special cases.

After a negative has been developed, it is fixed by soaking in a strong solution of hyposulphite of soda, or "hypo," as it is commonly called, which dissolves out all the unreduced silver bromide. Before fixing, however, it should be soaked for about a minute in a solution of alum. This has a tanning action on the gelatine of the emulsion, rendering it hard and less liable to peel off the plate. Further, a negative which has been treated with alum dries more quickly than a soft-filmed plate which has not been so treated.

The negative, after the alum bath and the fixing bath, is well washed and allowed to dry.

Examining a Negative.—Even when the greatest care is exercised both in exposure and development, negatives will sometimes be obtained in which the contrasts are very slight. This is especially the case in radiographing the abdomen. By holding the negative up to the light very little is to be seen on such negatives. More detail will be found by looking through the negative at a well-illuminated white surface; but the best method is to spread a piece of white glazed paper on a table, and lay the negative film side down on the paper. In a strong light many details will now be seen which would escape detection when using another method. The same effect may be obtained by placing the negative in a printing frame, spreading the white glazed paper over it as though it were printing paper, and fixing on the back. The whole is now portable, and may be examined in a strong light.

It is as well to remember that in looking at a negative in this manner, *i.e.*, looking at the film *through the glass*, all the parts will appear as in a print. The effect will be as though we looked directly at the part against which the plate was applied.

When the negative film is viewed directly, the image is reversed, and the effect is as though the part of the body which has been radiographed were viewed from the position in which the focus tube was working.

Printing.—Here, again, as in the case of development, instructions may be obtained from any manual of photography, so that no detailed description is necessary. Some processes are, however, better adapted to X ray work than others.

It often happens that a well-prepared print will reveal details which have not been seen in the negative.

No kind of rough or matt-surfaced paper should be used, as the object of printing is not to make an artistic picture, but to discover every detail of the negative which is possible. This can only be done on a well-glazed paper.

The gelatino-chloride, or printing-out papers, give the best results; and the printing should be done as slowly as possible.

The negative should be placed in the frame in the usual way, the printing-paper placed over it, then one or two thicknesses of blotting-paper, and lastly, the back. The blotting-paper acts as a cushion, and presses the printing-paper closely against the film. The actual printing should be carried out in good diffused light, and never in sunlight.

The so-called "special papers," whose object is to soften the results obtained from harsh negatives, are to be avoided.

In many cases it is convenient to have some means of preparing a print very rapidly. A developing paper must then be used. Either Nikko or Glossy Velox give good results if the instructions on the packets be carefully carried out.

If such prints are to be made frequently, a special set of dishes must be kept exclusively for the work, as absolute cleanliness is essential.

Localisation.—In the chapter on "Radioscopy" an account has been given of various methods by which foreign bodies may be exactly localised. Payne's method is only adapted for screen work, and the same may be said of Rémy's method so far as it is described on page 149. It can, however, be adapted to radiographic methods by using a special dark slide held in position over the patient by means of a clip.

Davidson's method, which involves the use of rather heavy apparatus, is described on page 125.

Barrell's Method of Localisation.—There are often cases in which a foreign body must be localised in some deep part of the body, and in which the screen methods are useless. Here Davidson's apparatus gives good results, but those who do not possess a special localiser will find that they can obtain results just as accurate by using a simple but scholarly method invented by Prof. Barrell.

His original idea was to find some workmanlike way of adjusting the focal point of the tube over a given point on the plate. He says: "In all existing methods of localising, the position of those points (the points on the plate perpendicularly beneath the focus) is ascertained by the use of a plumb-line, and in order to secure any accuracy in the results, the plate must be levelled before the skiagrams are taken: the use of plumb-lines is at all times 'fiddling' and annoying, and is specially so when the point from which the plumb-line *ought* to be suspended is an invisible 'focus' situated somewhere on the anode plate in the middle of a glass bulb".[1]

The only apparatus used by Barrell is a pair of metal cylinders 4 ins. long by 1 in. in diameter.

These are placed upright on the plate in such a position as not to interfere with the patient. When patient, plate and cylinders are in position the tube is adjusted, preferably over a part of the plate some distance from the cylinders, the distance from focus to plate measured with a tape and an exposure made.

The tube is next moved horizontally to some position 8 or 10 ins. from its original one, and a fresh exposure given.

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[1] *Archives of the Roentgen Ray*, iv., p. 99.

Plate XI.—Barrell's Method of Localisation.

On development and printing, the radiogram will have some such appearance as is shown in Plate XI. A and B are the shadows of the cylinders thrown by the first exposure.

If lines be ruled down the sides of these shadows, they all meet at M, which is the point on the plate which was directly beneath the tube-focus in its first position.

In the same way C and D are the shadows cast by the cylinders when the tube was in its second position. By repeating the process of ruling lines, we find M^1 the point on the plate which came perpendicularly below the focus, after the tube had been moved to its second position.

Turning our attention now to the shadows of the pin, S and S^1, we have only to rule lines from S to M^1 and from S^1 to M^1, and the point N where these two lines cross will be the point on the plate which was perpendicularly beneath the actual head of the pin when the radiogram was being taken.

The next step is to calculate the distance between the point thus revealed on the plate and the shot. This is calculated by the formula already given (page 145), *viz.* :—

$$x = \frac{d\ h}{d + l}.$$

Where x is the distance between the shot and the plate d is the displacement of the shadow of the shot S to S^1 ; l is the displacement of the tube M to M^1 ; h is the distance between the plate and the focus of the tube which was measured with a tape before exposure was made.

CHAPTER IV.

X RAYS IN DENTISTRY.

The usefulness of X rays to the dental surgeon depends on the fact that the teeth are very much more opaque to the rays than the osseous tissue in which they are embedded. A certain amount of information may be obtained by taking a radiogram right through the jaw, laying the patient with one side of his face on the plate. In this case, however, the faint shadows of the teeth on the opposite side will somewhat confuse the general appearance of the resulting picture.

The method always used nowadays for radiographing teeth is to place a film, suitably protected, inside the patient's mouth. Only one or two teeth can be shown at a time, but many details may be obtained which are impossible with larger plates. One of the first to take radiograms with a film in the mouth was Mr. Frank Harrison.[1]

In two papers read before the Odontological Society in April of this year (1900), by Mr. George J. Goldie and Mr. William S. Haughton respectively, a very complete account was given of a long series of experiments on the subject of dental radiography, "Nature of the Problems which may be Solved by X Rays". Mr. Goldie gives the following list of conditions in which he has used the X rays:—

(1) Fracture of the jaw.

(2) Fracture and dislocation of teeth in the jaw.

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[1] *Journal of the British Dental Association*, Sept., 1896.

(3) The diagnosis of inflammation round the roots of teeth —alveolar abscess—circumscribed and diffuse.
(4) The diagnosis of inflammation giving rise to symptoms remote from the seat of lesion, as neuralgia, etc.
(5) The diagnosis of impacted and incoming wisdom teeth.
(6) The normal eruption of the permanent teeth.
(7) Abnormal eruption of the same.
(8) The absence or presence of any given tooth in the body of the jaw when its eruption has been abnormally delayed.
(9) The progress of regulation of the teeth.
(10) Exostosis.
(11) Many purely clinical uses of X rays.
(12) Foreign bodies in the antrum of Highmore.

Films.—It is obvious that a film presents many advantages in the peculiar kind of radiography. Being thinner than a plate, it may be wrapped up in its envelope so as to form a very small parcel; moreover, its flexibility is a decided advantage. The amount of distortion obtained in ordinary work on a bent film is very considerable; but when an observation has to be made of so small an object as a single tooth, a certain amount of care in arranging the position of patient and tube will readily overcome this difficulty.

Any rapid film will give good results. I have been in the habit of using Austin-Edwards' snapshot films, but it is said that the cristoid films made by the Sandell Co. offer great advantages, especially in latitude of exposure. They are doubly coated with emulsion, one coat being rapid and the other slow, the object of this being to obtain a more complete absorption of the radiant energy of the tube.

A special film is also made in which both sides are coated with emulsion. This absorbs more of the radiant energy than a single film, and, seeing that both films are in the developer at the same time, the total density of the resulting negative is much greater than with a single film, however thick.

In dental work, however, there is no difficulty in getting good density. The depth of tissue to be penetrated is so small that very little diffusion takes place, and hence definition is usually good, and there is little tendency on the part of the film towards fog.

Small films are very cheap, so that it is best to buy them of the ordinary quarter plate size, $3\frac{1}{4} \times 4\frac{1}{4}$ ins., and cut them up with a pair of scissors. A quarter plate cut up into eight pieces makes a fairly convenient size, but a piece not quite so long ($1\frac{1}{4}$ ins.), is rather more manageable, and will in most cases be found large enough.

Envelopes.—The small films must be packed in light-tight envelopes similar to those used for the larger sizes of plates and films. These are best home-made, using paper cut from large yellow and black envelopes. Next comes the difficulty of protecting film and envelopes from the moisture of the saliva. Dr. Haughton's experiments on this subject are very interesting. He says :—

"The next difficulty was to render the film enclosed in its light-proof bags safe from the moisture of the saliva. This was easily done by using some form of india-rubber tissue. But here we were met by a new obstacle, because almost all samples of rubber are more or less opaque to the X rays owing to the sulphur used in its manufacture.

"The first material used was ordinary white mackintosh tissue ; this proved very opaque. Next india-rubber thumb-stalls ; the first lot used were satisfactory, but not so later batches. I next tried that fine sample of rubber used by dentists as a rubber-dam for the mouth. But this proved more opaque than anything previously used. Celluloid was also suggested, but the difficulties of ensuring waterproof sealing along the edges of the bag was very great. So finally a long correspondence with rubber manufacturers ended in getting a special bag made of almost pure rubber, which does not present very great opacity."

In the absence of these envelopes, the advice of Dr. Walsh [1] may be taken, *viz.*, to wrap up the film and paper envelopes in thin sheet rubber, and secure it by a few turns of sewing cotton. It must be remembered that sheet india-rubber often contains many substances besides caoutchouc and sulphur. The white varieties often contain china clay and sulphide of zinc, and the brown varieties, sulphide of antimony. I have used the semi-transparent dark-coloured sheet which is generally used for making the cases of pocket batteries, which contains nothing but vulcanised rubber, *i.e.*, rubber and sulphur.

In some cases this protective covering will be found unnecessary, as, for instance, in radiographing maxilliary incisors and canines, when the film can be held in position during the exposure without the envelope getting wet enough to have any effect on the emulsion.

Position of Film and Tube.—To quote again from Dr. Haughton's paper :—

"The anatomy of the mouth, more particularly in the relations of the roots of every individual tooth to the inner surface of maxilla or mandible, require a good deal of attention in order to be able so to place the film as to catch the shadow of the roots under examination without superposing on their shadow that of a neighbouring root. The curvature of the palatine surface of the maxilla, where the alveolus rounds off into the hard palate, is very difficult to negotiate, and usually results in a compromise : namely, if the general curvature of the film when moulded to the alveolus curve be roughly estimated as making an angle of 45° with the axis of the root, then to maintain perpendicular incidence of the rays on the

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[1] *The Roentgen Rays in Medical Work.*

film they must be passed through the cheek at an angle of 45°.

"A clamp to hold the film steady was very desirable. But amongst all the forms of mechanical clamps suggested I have found none answer so well as the finger of a skilled and steady assistant holding the film against maxilla or mandible, and the other hand making counter pressure outside.

"The head is best controlled at rest in the ordinary head-rest of a dental chair. The eyes being fixed on a suitable point in the line of vision helps towards the same end, while the assistant's outer hand completes the fixation of the head as far as possible.

"The distance from tube to film is given as from 8 to 10 ins."

An alternative method, which has been found satisfactory is to let the patient lie on an ordinary couch with his head thrown well back on a soft pillow. The film and tube are then placed in the positions recommended by Dr. Haughton, and it will be found fairly easy to hold the patient steady during exposure.

Exposure.—A somewhat hard tube may be used so that the bone of the jaw may be easily penetrated. Dr. Haughton gives exposures from 90 seconds to 2 minutes with an 8-in. Apps coil. If, however, a 10 or 12-in. coil be used, the exposure will be considerably shortened. I have been accustomed to use a 10-in. coil with a tube which gave an alternative spark of 4 ins. My exposures have varied from 20 to 40 seconds.

Screen Work.—Teeth are not at all easy objects to see with the fluorescent screen, though it is possible that by using hard tubes and Davidson's stereoscopic screen something might be done.

At present there are two methods adopted for making screen examinations of the teeth. Kolle's "dentiaskiascope" is an aluminium tube, at the end of which is a mirror inclined at an angle of 45° with the axis of the tube. On the side of the tube facing the mirror is a fluorescent screen. Any shadows shown on this screen may be seen, after reflection, in the mirror.

The other method is to use a small screen made with a handle like a dentist's mirror. The screen is backed with ebonite, and the fluorescent surface covered with transparent celluloid. The screen is held inside the mouth with the fluorescent material facing the teeth. The work is carried out in a dark-room, and the shadows of the teeth may be seen with fair distinctness.

Neither of these methods gives such satisfactory results as the photographic film.

CHAPTER V.

X RAYS IN CHEMISTRY.

UNDER this heading it is intended to group together several uses for the X rays which have been employed in scientific work, and which will probably become more widespread as they are better understood.

Metallurgy.—Perhaps the most important metallurgical work which has been carried out by means of the X rays has been in the investigation of the structure of alloys.

In October, 1898, Messrs. C. T. Haycock and F. H. Neville read a paper before the Chemical Society describing the structure of the alloys formed by gold, silver and copper with sodium and aluminium. Their object was to show that when alloys were allowed to solidify slowly, they went through a series of changes very similar to those which took place when aqueous solutions of various concentrations were slowly cooled down below the freezing-point.

In this place we are only concerned with the practical details of their X ray work. Those who may be interested in their results are referred to the original paper in the *Journal of the Chemical Society* (October, 1898, p. 714), where some beautifully reproduced radiograms will be found.

Their method of procedure is described as follows: "The alloys were usually allowed to cool and solidify in cylindrical crucibles, the solid cylinders thus obtained being nearly 1 in. in diameter, and from 2 to 4 ins. long. Vertical and horizontal sections of these cylinders were cut, and, when possible, turned down to a thickness of less than a millimetre and polished. These sections were laid on an Ilford plate enclosed in a light-tight envelope, and exposed to the Roentgen rays for periods varying from five minutes to an hour."

The easily oxidisable alloys, such as those containing sodium, were treated in a slightly different manner. After giving details as to the preparation of the alloy and the cutting of the sections, the authors continue: "Each section was immediately placed between thin sheets of very thin aluminium foil, and the edges sealed with melted paraffin. Thus each section was in an air-tight cell, and could usually be preserved for some weeks without serious oxidation."

All the sodium gold alloys were photographed by means of a Crookes' tube excited by a Ruhmkorff coil giving a 6-in. spark, the exposure varying from 5 to 30 minutes, according to the amount of gold present.

Defective Castings and Weldings.—Various attempts have been made to press the X rays into the service of engineers who wish to test castings and weldings for flaws. Attention has already been called to Roentgen's radiogram of a gun barrel. Other experimenters have radiographed the tubes used in the construction of bicycles, but, so far, only the thinnest of metallic structure can be easily penetrated, so that very little practical success has been attained in this line.

Adulteration.—In the earlier days of the X rays many suggestions were made for using their penetrative powers in the detection of certain kinds of fraud. The method has never become general, though it may prove of some service in discriminating between real and imitation jewellery.

In any case where the X rays could conceivably be of service in the discovery of adulteration, chemical methods would be more certain. One instance will suffice. A substance which frequently passes through the hands of an analyst is the ground bone used as a manure. The value of this substance depends on the quantity of phosphorus and of nitrogen which it contains. Useless substances such as vegetable ivory have been sold in its stead or used as an adulterant. The difference between the transparency of the bone and the organic matter renders it easy to distinguish between the two substances; but chemical methods are so obvious and so accurate that there is nothing to be gained by using X rays. Another case in which X ray work has been suggested is the detection of mineral colours in tea and sweetmeats.

Jewellery.—Plate I. in this book shows the radiogram of a lady's hand, with a diamond ring on one of her fingers. It will be noticed that although the rays were stopped by the gold, they have readily passed through the stones. As lead is used in nearly all the pastes from which artificial stones are made, it is easy to distinguish between a real and an artificial diamond.

The same is true for most precious stones, such as the ruby, the emerald, the sapphire, and so on, which are much more transparent than their imitations. The pearl, on the other hand, which is imitated by a bulb of thin opalescent glass, coated internally with a preparation made from fish scales and filled with wax, is less transparent than its imitation.

Another and more subtle way of imitating gems, so that the fraud cannot be detected by a file, is to make a "doublet" or "triplet". The paste is faced above (doublet), or both above and below, with a thin sheet of the true gem cemented to the composition, so that the joint is invisible. An X ray photograph will easily show up this fraud.

Mr. Foljambe Streeter has carried out experiments on this subject, but has, I believe, abandoned the method as less convenient than the optical and mechanical tests used by expert jewellers.

CHAPTER VI.

X RAYS IN WAR.

SINCE November, 1895, there has been ample opportunity for testing the efficacy of the X rays as a help to surgeons in war. Turkey and Greece have been at war, so have America and Spain, whilst England has had three campaigns on a large scale in North-Western India, Egypt and South Africa.

The Græco-Turkish war was the first in which the X rays were given a thorough trial. The *Daily Chronicle* organised and sent out a medical expedition to help the Greeks. This was placed under the charge of Mr. F. C. Abbott. A complete set of X ray apparatus went with the expedition, and was worked by Mr. Le Couteur. On his return Mr. Abbott published a full account of his work in the *Lancet*. Most of the report is taken up, of course, with descriptions of his surgical work, but sufficient is said concerning X ray work to give an idea of its value. The general result being that a portable apparatus taken on to the field is useless, whilst its greatest value is in the nearest hospital to the front.

The summary at the end of the report contains the following paragraphs :—

"The Roentgen rays should always, if possible, be available at that hospital nearest the front in which the wounds can be first properly examined and dealt with.

"The electricity should be derived from a secondary battery, consisting of separate covered cells, charged from the nearest man-of-war or other steamer, or by means of a cycle motor, as has been done in the Soudan by Major Battersby, R.A.M.C.

"Skiagrams should be taken on Eastman's positive paper, which is sufficiently satisfactory for the detection of foreign bodies.

"The apparatus is of no use in the field where the detection of bullets can only be an incentive to premature exploration."

In the Spanish-American war X ray apparatus was very generally used, though, instead of relying on the paper skiagrams which Mr. Abbott had found so useful, the American surgeons, wherever possible, used a fluorescent screen, making accurate measurements of the position of bullets by means of an apparatus similar to the one described on page 145, but instead of measuring by means of compasses and a scale, the screen was mapped out into squares by lead wires.

In English campaigns X rays have been used successfully under very varying conditions. Major Beevor, R.A.M.C., used the apparatus in the Indian Frontier war, and Major Battersby, R.A.M.C., used it in the Soudan. The latter, on his return, read a paper before the Roentgen Society recounting his experiences, and Major Beevor at the same time mentioned a few of his successes and difficulties. A sentence from Major Beevor's speech gives an idea of conditions under which surgical work has to be carried out in the British army. He is reported thus:—

"The results obtained by Major Battersby showed that X ray apparatus could be worked successfully in hot climates. In the Indian Frontier war most of the work was done during very cold weather among the mountains. They had one accident with the induction coil at starting, when the paraffin wax was melted during transit in the railway train, and wet blankets were resorted to to keep the coil cool."

Major Battersby's account is the most complete which has yet been published of actual experiences in warfare. He seems to have had time to obtain special apparatus before leaving England, and thus made many ingenious arrangements. As some of these may be of use to X ray workers in hot climates, I quote the following descriptions of special apparatus from his paper :—

"Before leaving Cairo I took the precaution of having very thick felt covers made to surround the outer boxes containing the coils and storage batteries, and by keeping these constantly wet the internal temperature was considerably reduced, as evaporation in the Soudan is very rapid. Between Wady Halfa and Abadieh all my apparatus had to travel for two days and a night in an open truck, exposed during the daytime to the fierce heat of a blazing sun. By keeping the felt wet every two hours we reached our journey's end without mishap; thermometric observations later on proved that when the felt coverings were kept damp the temperature in the centre of the coil did not exceed 85°. . . .

"The Roentgen ray outfit which was sent out to the Soudan consisted of a 10-in. coil, made by Mr. Dean of Hatton Garden. This coil was specially insulated, and, with condenser, commutator, interruptor, volt-meter, small electric lamp, fluorescent screen, and two focus tubes, was enclosed in a strong oak box. It was most complete and satisfactory, but for the requirements of field service too heavy for camel or mule transport. Consequently I had a special arrangement made, by which means and by the aid of a long pole it could be carried on the shoulders of four men, like an Indian dhoolie.

"Another 10-in. coil, designed by Mr. Apps, also accompanied me. At my suggestion, this coil consisted of two separate parts, the coil proper being enclosed in a teak case, and the condenser, commutator, contact breaker, etc., in another. By this method the weight was evenly divided, and the two boxes could be readily carried on either side of a mule or camel, or by coolies, over very mountainous districts. . . .

"In addition, a small 6-in. Dean's coil accompanied me to Omdurman from Abadieh."

Major Battersby's method of generating electricity by means of a tandem bicycle has become quite classic, and is described on page 36.

To give an idea of Major Battersby's success, the following details may be quoted from the same paper :—

"After the battle of Omdurman 121 British wounded were conveyed to the surgical hospital at Abadieh. Of this number there were twenty-one cases in which we could not find the bullet or prove its absence by ordinary methods. In twenty out of these twenty-one cases, an accurate diagnosis was arrived at with the help of the rays, the odd case, a severe bullet wound in the lung, being too ill at the time to examine."

Of X rays in the Transvaal war we shall doubtless hear more when the war is over. Many sets of apparatus were taken out, the hospital ships being especially well installed. At first the apparatus, with very few exceptions, was in the hands of surgeons, but later on a number of gentlemen were sent out, having a special knowledge of the X rays and X ray apparatus, to devote themselves entirely to this class of work.

The war in the Transvaal has been one in which engineering equipment has been supplied on a very large scale. Electrical engineers, with their apparatus for generating electricity, have been always at work. Thus the radiographers have been free from the greatest difficulty encountered by those who have to use X rays in war time.

Throughout the war, accounts have been sent home telling of the surgical work in South Africa. All agree in giving high praise to the help which X rays have given both in the localisation of bullets and in the exploration of bone injuries. The apparatus used is invariably a 10-in. coil, though no standard pattern has been decided upon.

The difficulties of transporting X ray apparatus and keeping batteries in order at a distance from sources of power have by no means been overcome. The experience of the Boer war has helped us very little in this direction. Indeed the expeditionary force in East Africa has had to fall back on the clumsy device of carrying a large bichromate battery. This, with the materials for charging, has to be carried by the men.

We may, however, look forward to a time in the near future when engineers will take this question in hand seriously. So long as the use of large coils was confined more or less to the medical profession, electricians were apt to neglect its development. Now, however, that wireless telegraphy, with its need for sparking coils, has become a practical success, the attention of practical men is being called to the fact, that not only war surgery but also war signalling make it imperative that we shall have some easily movable source of electricity.

No doubt the demand thus caused will create the necessary supply.

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GROUP III. Animal Raw Materials. Animal Wool and Hair—Sheep's Wool—Goat Wool—Camel Wool—Llama and similar Wools—Cow Hair—Poodle Hair—Hare, Rabbit, Cat and Beaver Fur—Horse Hair—Bristles—Silk—Natural Silk—Artificial Silk—Byssus Silk—Detection and Estimation of Textile Raw Materials in Yarns and Fabrics—Characteristics of Mineral Raw Materials—Detecting and Methods of separating Vegetable and Animal Raw Materials in general—The Combustion Test—The Mandarin Test—The Picric Acid Test—The Sulphuric Acid Test—The Alkali Test—Differentiation of Animal and Vegetable Fibres in detail—Characteristics of Cotton—Characteristics of Flax—Characteristics of Sheep's Wool—Characteristics of True Silk—Characteristics of Artificial Silk—Determining the Constituents of Textile Fabrics—The Detection of Cotton in Linen Fabrics—The Detection of Cotton in Woollen Fabrics—The Detection of Cotton in Silk Fabrics—The Detection of Wool in Silk Fabrics—The Detection of Wild Silk in True Silk Fabrics—The Detection of Artificial Silk in Silk Fabrics—The Detection of Byssus Silk in Silk Fabrics.

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